CHAPTER 8

IMPLICATIONS FOR PRE-SERVICE K-6 TEACHER EDUCATION, AND LEARNING OF K-6 SCIENCE

8.1 REVISITING THE AIMS

The primary aims of this research were to:

- Identify and isolate fundamental electric and magnetic concepts, an understanding of which is desirable in students at the completion of their K-6 education;
- Investigate pre-service K-6 teachers knowledge and understanding of the identified fundamental concepts;
- Develop an instrument to overcome perceived barriers to the participants' effective learning of the concepts;
- Explore strategies to improve teacher confidence; and
- Provide a useful resource to develop fundamental understanding in K-6 students about specific science concepts.

A common framework is presented, the research questions are revisited, and the emergent themes are mapped and discussed. The chapter concludes with set of proposed ideas for future investigation.

8.2 A COMMON FRAMEWORK

From a practical standpoint the results of this research are most usefully presented in a context and manner that addresses an audience of pre-service teachers, teachers, and those responsible for pre-service science teacher education.

Three major areas were identified by this project, and supported by the literature, as underpinning pre-service K-6 teacher education in the science Key Learning Area:

- Content knowledge defined by the syllabus;
- Knowledge of a variety of pedagogies, and their application; and
- Confidence to combine the above into effective learning experiences for learners.

Figure 8.1 presents a visualisation of how the relationship and interplay between these three areas, contributes to the preparation of an effective classroom practitioner.

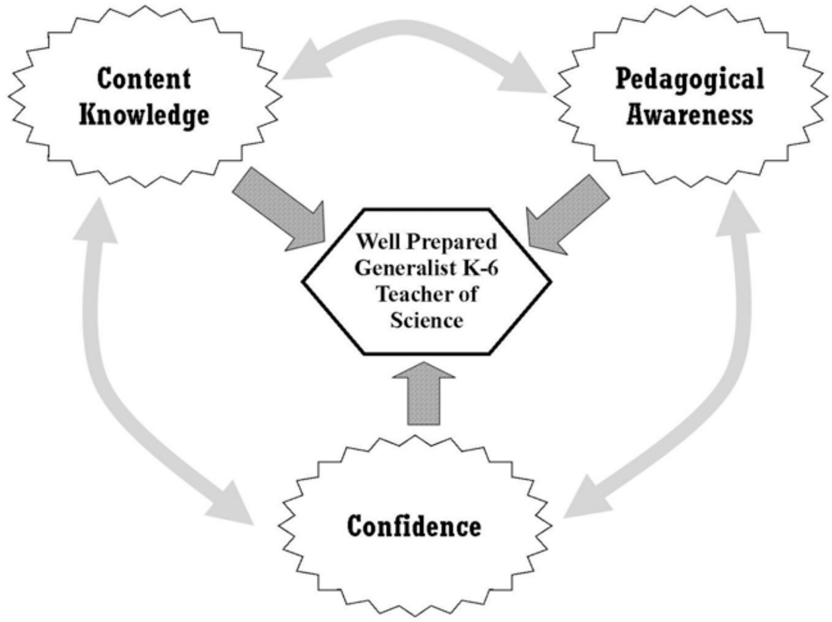

Figure 8.1: A diagrammatic representation of the common framework showing the relationship between the three identified areas underpinning the education of pre-service generalist K-6 teachers.

8.3 REVISITING THE RESEARCH PHASES

To select a vehicle to conduct this study, the research team considered all areas of science study defined by the NSW K-6 Science and Technology Syllabus (BoS NSW 1993). As today's society is becoming increasingly reliant on electricity, magnetism and their interactions, for example communication, entertainment, medicine, manufacturing to name but a few, the learning of fundamental electric and magnetic phenomena was chosen.

To meet the aims described above, four phases were designed and conducted to investigate six research questions. Following is a brief outline of each of the phases.

8.3.1 Phase I – Expert Interviews

Semi-structured interviews were conducted with a group of experts to identify **fundamental concepts** of electricity and magnetism, and **barriers** to their effective teaching. These findings informed the genesis of the initial instrument.

8.3.2 Phase II – Assessing and Enhancing Understanding and Confidence – Initial Instrument

Surveys and observations, with a cohort of second-year pre-service K-6 teachers, established their **initial understanding,** and **variation in understanding,** of the identified fundamental concepts. The relationship between the variation in understanding, and **confidence** to teach those concepts, was explored. A sequence of learning experiences, containing specific interventions, including **modelled teaching strategies** and **hands-on exploratory activities**, was designed and undertaken. The sequence was evaluated in terms of the effectiveness to improve conceptual knowledge and understanding, and overcome recognised barriers that impact on pre-service teacher perceptions of 'lack of confidence' to teach the concepts.

8.3.3 Phase III – Refined Sequence

A final sequence, incorporating changes recommended by Phase II, was qualitatively and quantitatively assessed in terms of its **effectiveness to enhance conceptual understanding,** and to **build pedagogical confidence.** To provide validation of the instrument, the refined sequence was undertaken by a different cohort of pre-service K-6 teachers.

8.3.4 Phase IV – Peer-Teaching

This phase provided the opportunity to evaluate particular elements of the sequence, delivered in a realistic classroom situation, as a learning tool with a whole class, and as a teaching tool with small groups of learners. The phase comprised two components.

- A cohort of fourth-year pre-service K-6 teachers, working collaboratively in small-groups, investigated, through a rotation of activities, elements of the refined sequence. The focus of each of the activities was to **explore formative assessment** as a means to guide future learning as a teacher tool, and experience **collaborative learning** while considering their own learning processes.

- Volunteers from this cohort acted as 'teacher/observer' pairs to select, prepare and **present hands-on, open-ended, problem-solving activities** to small groups of second year pre-service teachers to achieve **defined outcomes**. These peer-teaching sessions culminated in an evaluation of the applicability of the selected activities in a simulated classroom situation, the **value of formative assessment** to guide future teaching/learning strategies, and to consider any **changes in 'teacher' confidence** as a consequence of the experience.

8.4 RESPONDING TO THE RESEARCH QUESTIONS

To measure the success and scope of this research project, we revisit the six research questions set out in Chapter 1.

8.4.1 Research Question 1

> *From a broad community context, what are fundamental key concepts in the study of electricity and magnetism that should be explored by K-6 school students?*

The distillation of twenty-three expert interview responses led to the selection of the four fundamental concepts for exploration during subsequent phases of this project. They were:

- Safety with electricity;
- Efficient energy use;
- Efficient energy generation; and
- The motor effect.

The relationships between these concepts can be visualised diagrammatically as in Figure 8.2.

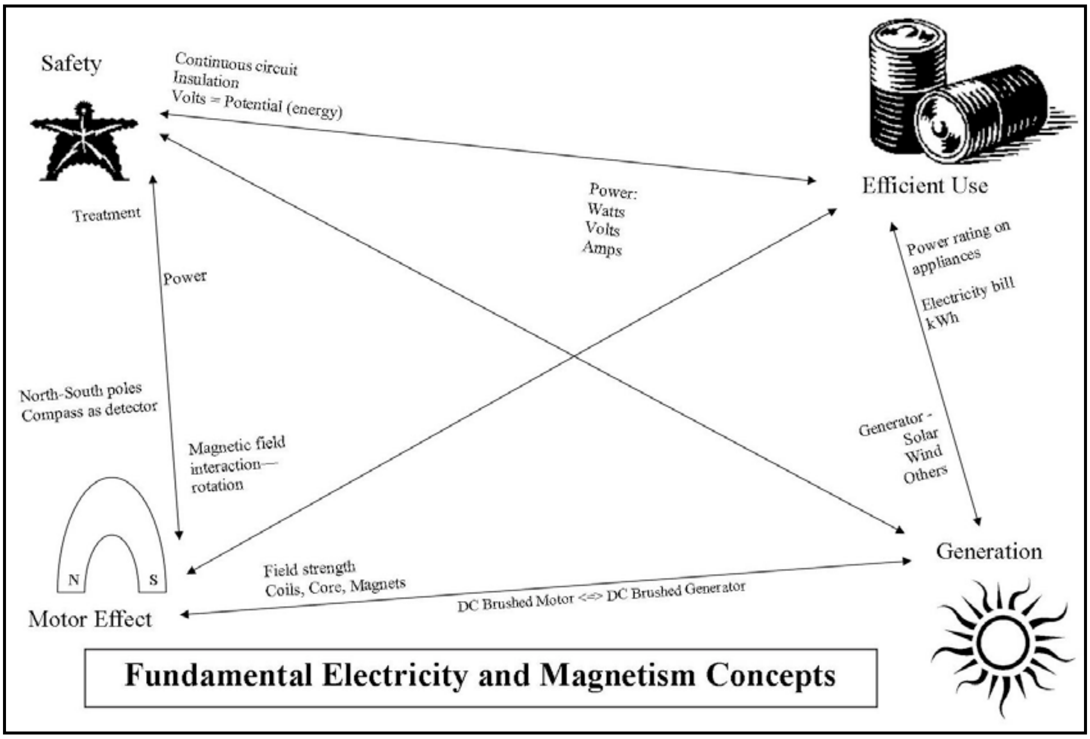

Figure 8.2: Links between the four Phase I identified fundamental concepts.

- **Safety –** the significant proportion of childhood death and injury resulting from accidents involving electricity was expressed as a major concern. This finding led to the recommendation of greater emphasis being placed on safety with electricity in the K-6 years of schooling, by exploring the insulative properties of materials. It was suggested that a hands-on, activity-based approach would be most effective at reinforcing the desired understanding.

- **Efficient use of electricity –** electricity 'waste' by society in general, and school-age children in particular, was identified as a commonly expressed problem. An awareness of ways to decrease electricity use was therefore recommended as a desirable outcome of K-6 schooling. Identifying inefficient appliances; understanding of the meaning of energy ratings on appliances and therefore the costs of running appliances (as reflected in the household power bill); were suggested as possible inclusions in the curriculum, to achieve this outcome. Coupled with this, participants identified a need for K-6 students to be aware of where electricity 'comes from', and that there are costs (financial and environmental) associated with its generation.

- **Efficient generation of electricity –** respondents linked electricity use with electricity generation, suggesting that in order to promote energy (electricity) conservation at a household and personal level, students should explore different ways of generating electricity, and the impact that electricity generation has on the environment.

- **The motor effect –** a fuller understanding of the generation and use of electrical energy was recommended by respondents who suggested that simple, hands-on, exploratory activities should establish a conceptual understanding of how motors and generators work. Consideration of ways to investigate, this led to the construction of the initial sequence of activities to explore '*moving a magnetic field can make an electric current*', and '*electric current makes a magnetic field*', undertaken during subsequent phases of the project.

As pre-service K-6 teachers were the primary data source for the latter phases, the modelling of strategies to conduct effective investigations provided the context for the development of the initial and refined research instruments.

8.4.2 Research Question 2

What are the perceived barriers that may limit the successful teaching and learning about fundamental electric and magnetic phenomena?

The phenomenological analysis stages of the study identified difficulties perceived by the experts, and a list of real difficulties identified/experienced by the pre-service teacher participants.

The initial Expert Interviews phase provided an insight into why electric and magnetic phenomena are not receiving particular attention in K-6 classrooms. It revealed a commonality of perceived belief that science in general, and electric and magnetic phenomena in particular, are not being effectively taught in K-6 schools by a significant proportion of teachers. This opinion was qualified by references to: poorly equipped teaching spaces; a confusing and difficult to use syllabus; irrelevant content defined by the syllabus; and the apparent low priority placed on the teaching of science justified by the need to emphasise literacy and numeracy due to mandated external examinations. The majority of the experts, emphatically stated that their school experiences with electric and magnetic concepts had not, or had only minimally, contributed to any understanding applicable to their vocation, or life experience.

In response to this, the pre-service teacher participants' experiences of science learning in school were explicitly identified during Phases II and III. It was revealed that the majority of students had not studied any science beyond the compulsory years of schooling. Reasons referred to a perception that science was: 'boring' because of the way it was taught to them; irrelevant to their interest and experience; too difficult; and not as important as 'maths' or 'English'. Due to a lack of knowledge about science, many stated they would probably resort to transmissive pedagogies with which they felt safe and familiar, or avoid teaching it at all.

Some of the identified barriers are common to both experts and pre-service teachers. Others were particular to the perceptions of the different groups. The barriers identified are summarised and presented in Figure 8.3.

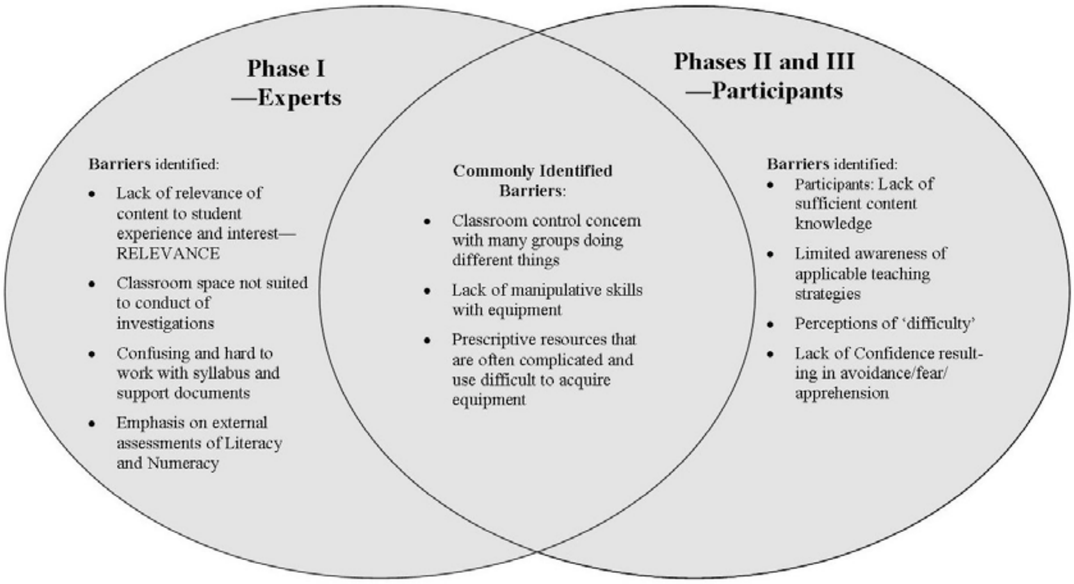

Figure 8.3: Barriers to the successful teaching of science to K-6 students as identified by Phases I, II and III.

When considered as a whole, the perceived barriers may be categorised into:

- Insufficient teacher background content knowledge;
- Lack of relevance of content to learners' experience and interest;
- Difficult to present activities requiring hard to acquire, or difficult to use equipment;
- Loss of overall control of classroom while implementing 'experimental' activities;
- Confusing and poorly planned syllabus and support documentation;
- Undervalue of science as a Key Learning Area; and
- Limited awareness of teaching strategies to facilitate scientific exploration and investigation.

A different categorisation leads to recommendations to address the barriers with responsibility falling on (but not limited to):

- Education authorities:
  - Provide professional support to existing teachers;
  - User friendly syllabus and support documentation; and
  - Emphasis on the need to teach science by promotion of its value to society, or even mandating external assessment.
- Pre-service teacher education providers:
  - Modelling of range of pedagogies to meet the needs of range of teachers strengths and teaching approaches;

- Experience with, and opportunity for, reflection of effective science teaching strategies – not just as a 'hit and miss' part of a loosely supervised practicum;
- Opportunity to deliver investigative, hands-on exploratory activities using simple to use and readily available resources in generalist classrooms; and
- Emphasis on the need to teach science as part of a well-balanced approach to generalist education by promoting its relevance.

8.4.3 Research Question 3

Within the context of pre-service K-6 teachers, what are the variations in the understanding of the identified fundamental concepts?

During the initial components of Phases II, III and IV, when presented with content based questioning, the majority of the pre-service teacher participants demonstrated a poor level of content knowledge about electric and magnetic phenomena. It was revealed, however, that their knowledge about common aspects of electric phenomena was better than that of magnetic phenomena.

The limited understanding of fundamental concepts of electric phenomena was categorised in relation to simple circuit construction, models of the flow of electricity through circuits, the generation of electricity, the insulative properties of materials, and the meanings of commonly used terms such as voltage, amps, watts and kilowatt-hours.

Analysis of the pre- and post-intervention surveys revealed a significant increase in the level of conceptual understanding, and decrease in the demonstrated variation. An awareness of the need for continuity of conducting pathways for electricity flow was strongly evident at the completion of the sequential activities, yet missing in the pre-intervention surveys. Similarly, an understanding of the different conductive properties of metals and insulating materials was not evident among the majority of pre-intervention responses. However, in the post-intervention responses, understanding of the concept was manifest in statements relating to the need to ensure that electrical appliances are appropriately insulated from the user, to avoid electric shock. Responses also highlighted precautions that should be taken during electrical storms, particularly with respect to downed power-lines. A professed increased understanding of the implications of efficient electricity use was also expressed, although some stated that the mathematical nature of annotations on power-bills was still an area of limited understanding.

Participants also demonstrated an increased awareness of the ways that electricity may be generated, and identified the reversible relationship between electric generators and the motor effect.

The knowledge of the application of magnetic phenomena to everyday devices was limited to, for the most part, the attractive properties of magnets in the pre-intervention survey responses. Confusion with respect to the polar nature of magnets was identified, with approximately half of the participants stating that magnets had positive and negative ends. Very few acknowledged the role that magnetism plays in the generation of electricity, or in electric motors. The assessed level of fundamental understanding about magnetic phenomena was higher in the post-intervention responses. Participants successfully identified the 'north' and 'south' polar nature of common magnets, the attractive and repulsive combinations, and were able to explain the working of a compass – previously not identified by almost all, as a suspended magnet. Significantly, most respondents clearly identified the relationship between moving a magnet inside coils of wire as generators of electric current, and the converse, electric current flowing in a coil creates a magnetic effect. Most were able to explain that the interaction of magnetic fields, whether induced or permanent, was the conceptual understanding needed to explain the motor effect.

These findings guided the construction of the initial sequence of activities as a means to address the identified 'shortcomings' in conceptual understanding. Analysis of the degree of enhancement of the understanding achieved by the initial instrument resulted in modifications to some activities, and the incorporation of others in the refined sequence. For example, additional activities relating to the concepts of: insulation; the relationship between electric motors and generators of electricity; magnetic polarity; and magnetic pole interaction causing rotation, were included.

Changes to the modelled teaching strategies involved the incorporation of overtly demonstrated formative assessment strategies, and collaborative activities requiring peers to explain their observations of, and explanations for, particular phenomena. Analysis of the Phase III findings indicates that learners are more willing to build conceptual understanding if it involves the assimilation of experiential and negotiated explanations of concepts into their existing knowledge structures. This in preference to a situation where they try to modify their personal internal knowledge structures in isolation. As one participant put it,

> *"We owned the knowledge constructed in this way. It was not something owned by someone else, the teacher, and borrowed by us until we forgot it."*
> (SID P4P1W3GLt119)

8.4.4 Research Question 4

How is the variation in understanding of the identified fundamental concepts of electricity and magnetism reflected in the confidence level of pre-service K-6 teachers to teach them?

Participant confidence to teach the defined concepts was investigated several ways:

- Conceptual knowledge and understanding was assessed using the pre- and post-intervention surveys, and the responses recorded in the interactive workbooks;
- Observations made by the members of the research team qualitatively measured:
    - Engagement with the prescribed activities increased over the duration of the intervention activities, in terms of participants contributing to discussions in a positive and co-operative manner;
    - Enthusiasm exhibited to share observations and explanations as part of the Predict-Observe-Explain-Share activities increased as reticence to express an opinion diminished, once a collaborative environment was established and maintained; and
    - Degree of competence demonstrated in terms of manipulating apparatus and equipment used during the hands-on exploratory activities as demonstrated by participants undertaking additional investigations beyond those prescribed by the intervention activities.
- Reflections made by the participants during the small-group interviews. These described:
    - An increased level of engagement with the prescribed activities as a consequence of perceived relevance and/or interest;
    - Enthusiasm to participate in the Predict-Observe-Explain-Share activities was identified by participants themselves;
    - Excitement and enjoyment expressed, individually and collectively, as evidenced by the behaviour of other group members;
    - Willingness to try other permutations and applications of the activities and equipment being used, exemplified by some conducting self-designed investigations of phenomena being explored, for example, conductivity of common materials.

Key contributors to increasing confidence in pre-service participants were, therefore:

- Increased level of understanding;
- Identification of activities that promote excitement and enjoyment in learners. This was particularly identified as a consequence of the successful completion of tasks perceived as relevant to the learner;
- Recognition of the transfer of learning exemplified by effective collaborative learning strategies; and
- Recognition of improvement of ability to manipulate equipment necessary to demonstrate fundamental phenomena.

It is interesting to note that some participants indicated that although their levels of knowledge and understanding had been significantly enhanced, their increased knowledge highlighted to them how much more they felt they needed to know and/or understand, before they could feel confident that their knowledge level was at a personally identified adequate level.

The participants, after Phases II and III, demonstrated an increase in conceptual understanding and awareness of teaching strategies. Both of these were reflected in an increase in self-perceived competence to teach the fundamental concepts due to an improvement in confidence to apply the strategies experienced during the sequence components.

8.4.5 Research Question 5

Does the integration of Predict-Observe-Explain-Share strategies into the 5Es pedagogical model provide an effective means to support and enhance K-6 pre-service teachers' learning of fundamental concepts?

Within the context of the 5Es (Australian Academy of Science 2007) learning cycle, the Predict-Observe-Explain-Share activities were employed to model the first two phases:

- **Engage**: capture interest and provide an opportunity for the learner to personally identify what they know about the concept being explored, through their own observations and the shared observations of others, thereby helping them to make connections between what they know and the new ideas; and

- **Explore**: hands-on activities in which they can investigate the concept or skill. They grapple with the problem or phenomenon and describe it in their own words. This phase allows students to acquire a common set of experiences that they can use to help each other make sense of the new concept or skill.

The elements of the Predict-Observe-Explain-Share strategies may described as:

- **PREDICT**: describe what is the expected outcome of a specified activity;
- **OBSERVE**: record observations of the actual event. These may be qualitative or quantitative;
- **EXPLAIN**: record an explanation of what happened in the observer's own words, identifying any variation between the predicted and actual observation; and
- **SHARE**: discuss the variation in observation and explanation in small-groups of peers, negotiating meaning, and eventually arriving at an agreed, shared explanation.

The Predict-Observe-Explain-Share activities selected for exploration, and the reiterative nature of the sequential elements, were informed by Vygotsky's premise that effective learning only occurs within an individual's Zone of Proximal Development (ZPD) as a consequence of personal experience, coupled with interaction with a more able individual (Vygotsky 1978). The link between the reiterative elements of the sequential components and Vygotsky's learning model may be visualised diagrammatically as presented in Figure 8.4.

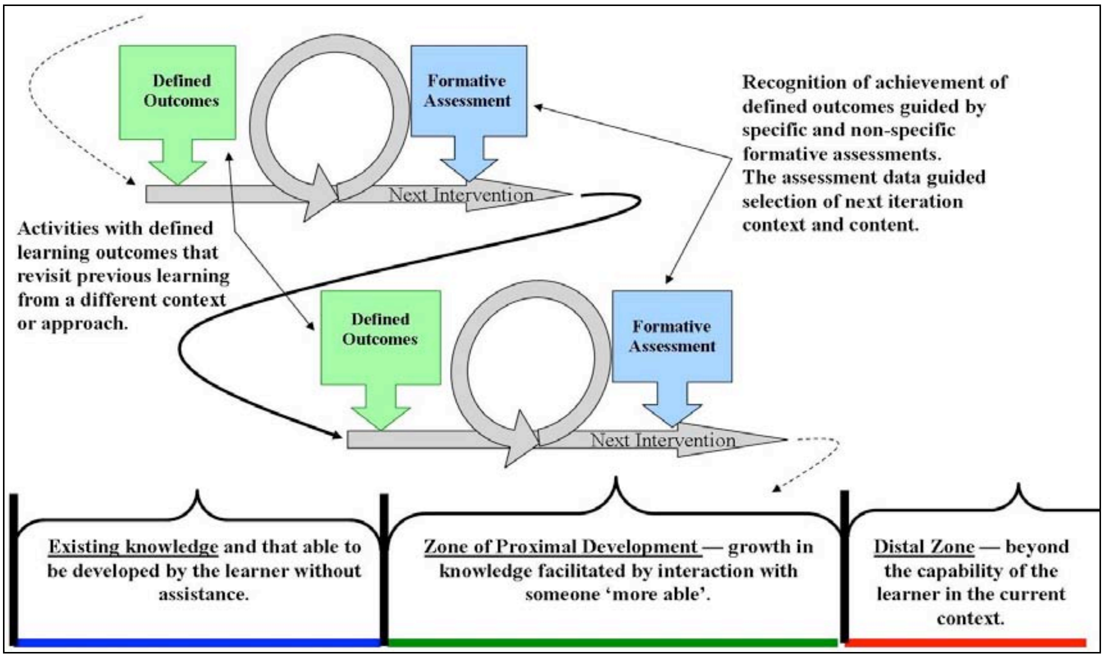

Figure 8.4: The components of the sequence expressed as reiterative Predict-Observe-Explain-Share elements (loops), aligned with Vygotsky's Zone of Proximal Development.

Analysis of participant observations, individual explanations, and explanations negotiated as part of the collaborative process, facilitated a comparison of the individual and negotiated explanations to provide a means of qualitatively measuring conceptual change. It was revealed that some of the Predict-Observe-Explain-Share activities were more effective at facilitating change than others. In constructing an affirmative response to Research Question 5, it must be recognised that the more effective activities met two specific criteria:

- The exploration of the new activity began by extending the existing knowledge of the learner within the context of personal experience, or at least experience able to be identified as within the realm of the learner's imagination; and
- The concepts being explored could be linked to that knowledge and experience without the links being broken by extending the complexity into the distal zone, where no amount of peer or expert support will result in conceptual change in understanding.

Examples of the most successful Predict-Observe-Explain-Share interventions derived from simple, hands-on activities incorporating easily accessible materials where extrapolation of imagination was a feature. For example, the construction of electromagnets with a single variable promoted the investigation of other variables. Specifically, the participants identified, and chose to explore, the possible effect of increased number of turns of wire in the coil, the nature of the material making up the core of the electromagnet, the amount of the current passing through the coil, and the physical dimensions of the coil itself (length and diameter).

The less effective examples of the Predict-Observe-Explain-Share activities met only one, or none of the criteria. For example, the movement of the button magnet allowed to free-fall down an aluminium tube did not yield any satisfactory explanations of the observed phenomenon. This was identified as a totally new phenomenon in terms of the experience of the participants, and although the formation of eddy currents was explained during the demonstration, reference to this phenomenon in the guided activity workbook responses was limited to those participants who had undertaken tertiary physics study. Interestingly, the concept of a compass as a suspended magnet was not consolidated with the majority of participants until they undertook to build a model compass, demonstrating that there had not been a connection previously made between their experience, and the observation of the phenomenon of a magnetic needle aligning itself with a magnetic field.

The incorporation of the 'Share' component of the Predict-Observe-Explain-Share activities facilitated the maximum progression of the conceptual understanding through their individual Zones of Proximal Development. Comparing individual responses to the 'Explain' component, with those derived from peer-negotiated shared explanations identified this progression. The enhanced and identified competence of the participating 'teachers' during Phase IV, to implement and use formative assessment strategies, was linked to observations of specific behaviours, and responses to directed questioning. For example, 'observers' noted that the 'teacher' pointing out aspects of the observations that would construct further conceptual understanding could guide the 'simulated Year 4 students' toward the desired conceptual understanding. This was most apparent during the compass building activity in terms of the 'teacher' demonstrating what happens when another magnet is brought near the floating magnet, and then removed, highlighting the alignment of the compass with the 'strongest magnetic field in proximity'.

It is evident, therefore, that the Predict-Observe-Explain-Share activities are most effective when applied in a manner that is not in isolation, but provide an overlap of existing, or newly constructed knowledge; in other words, when the activities are not introducing new knowledge, but revisiting existing knowledge from a different perspective, in a different context. In order to maintain engagement with the process, it was pointed out to the participants, in terms of a teaching strategy, that the activities provided an opportunity to increase the depth of knowledge rather than reiterate the existing knowledge.

The modelled scaffolded activities prompted considered and reflective first-hand evaluation of the sequence elements, as a potentially effective teaching mechanism for the early career K-6 teacher. By empowering the participants to consider the reasons for the effectiveness, or otherwise, of the strategies they experienced, their awareness of the value of the integrated formative assessment, to facilitate the design, implementation and assessment of pedagogy, was also enhanced.

Several scaffolds (activities, prompts, guidelines and questions promoting individual and collaborative responses) were employed to move the understanding about electric and magnetic phenomena, identified by the pre-intervention survey, toward that recognised as more 'scientifically correct'. To participants who were apparently unfamiliar with electric and magnetic interactions, some of the activities were promoting a level of understanding that appeared to fall outside their Zone of Proximal Development. For instance, some students were able to identify the components of an electric motor, but were unable to link the concept of a brushed DC motor being used as a generator. The recognition of this by the participating 'teachers', during the peer-teaching sessions, led to directed discussions between the 'teacher' and the learner(s) about their understanding of specific concepts. This resulted in the consideration of comparisons between: what the learner knew to be true; what their peers were espousing; and how their personal understanding may change, if the alternate explanation provided by their peers, contributed to a change in understanding.

8.4.6 Research Question 6

Can a peer-learning inquiry-based pedagogy be adopted and used as a framework in pre-service science teacher education for learning and as a model for teaching?

This question was investigated primarily by the implementation of Phase IV – Peer-Teaching that comprised two components. The first entailed the modelling of the strategies identified as effective by the findings of Phases II and III. A rotational sequence of hands-on, problem solving Predict-Observe-Explain-Share activities was undertaken by a cohort of EDSE412 final-year pre-service K-6 teachers (for course details, see Appendix B). The second component sought volunteers from the same cohort to conduct small-group peer-teaching episodes with volunteers from the second-year cohort of EDSE213 pre-service K-6 teachers. This provided a mechanism to validate the additional activities, and identify any change in perceived confidence of the participants, to adopt these strategies early in their career. As described in Chapter 7, an anticipated outcome of this component was the conduct of constructivist teaching strategies by the volunteer 'teachers' with the second-year participants, facilitating the practise of the strategies to build competence (increased background knowledge and understanding), and confidence (first-hand experience of teaching strategies).

Participants undertaking Component 1 identified the rotational activities as effective at establishing and building their conceptual understanding of the fundamental concepts presented. It was also acknowledged that the reiterative nature of the sequence consolidated the understanding to a similar level regardless of the starting point. Feedback gleaned from the small-group interviews indicated that modelled strategies were simple and yet exciting, exploratory and yet not confusing, relevant and yet not repetitious in terms of previous knowledge or experience. Reflections enunciated during these small-group interactions revealed that this experience led to a greater awareness of the need for variety in pedagogical approach, to K-6 teaching situations. At the completion of the Phase IV peer-teaching sessions, the 'teachers' unanimously expressed a qualified and informed satisfaction in their teaching, and enthusiasm for adopting such an approach as teachers.

It is evident, therefore, that the peer-teaching opportunities promoted in the participating 'teacher(s)', an awareness of how the scaffolding of activities may contribute to learners' model construction and reconstruction. Hence, the 'teacher' was encouraged to consider what sort of activities facilitated learners in their small group, to challenge their personal beliefs, and how this contributed to the developed models of the concepts being explored. Furthermore, the participants reported that the small-group teaching sessions provided insight into the variations in the dynamics of students' interaction. The most common aspect of these related to the insecurity demonstrated by learners, when it became obvious to them, that their explanation of the phenomenon under investigation was 'least correct'. Participants reported that this observation was particularly valuable in terms of their awareness of the need to stress that there are no 'wrong' answers during the Predict-Observe-Explain-Share process, thereby contributing to the building of learner confidence.

It was reported in follow-up interviews that, once initial reticence stemming from the fear of being 'wrong' was overcome, the opportunity to participate in hands-on exploratory activities with small groups of peers, promoted engagement in, and enjoyment of, the activities. This highlighted the perception among participants that such an approach would contribute positively to the management of an active, yet controlled classroom environment, and result in less miscreant behaviour among learners, and improved learning opportunities. Most participants identified this as a positive contributor to their confidence in terms of their classroom/behaviour management skills, implying that the strategies would be most enthusiastically trialled in their classroom early in their teaching career.

The growth of awareness of formative assessment as a desired pedagogical tool, that enhanced the skills of the teacher, was reinforced during the peer-teaching component of the sequential activities. Such things as responding to questions that seek a broader explanation of observed phenomena, or observing increased psychomotor skills when completing hands-on activities, were strongly supported by those participants given the opportunity to practise their teaching. The 'teachers' identified specific behaviours and/or responses to prompts that indicated the achievement of increased skill, awareness, or understanding of the desired concepts or abilities.

8.5 DISCUSSION

K-6 teachers tend to place a low priority of the teaching of science and are apprehensive to teach it, perceiving science as a hard 'subject' to learn, and therefore teach, and irrelevant. Pre-service K-6 teachers have a limited knowledge of fundamental science concepts, and this is linked to a lack of confidence to present science-based activities to their students. Modelling research verified learning cycles and teaching strategies leads to an awareness of engaging, inquiry-based explorations of intrinsically relevant and/or topical science concepts. As pre-service teachers, the witnessing, and active participation in the teaching of fewer concepts, introduces a suite of pedagogical tools, and confidence to apply those tools, from the beginning of their K-6 teaching career. The construction of formative assessment strategies, as an integral component of teaching plans, encourages an awareness of individual learning needs, and facilitates the development of remediatory experiences that reinforce the desired conceptual understanding. The implementation, in classroom situations, of collaborative learning strategies provides opportunities for 'owned learning' to be constructed by the individual learner, often as a consequence of negotiating an explanation of the observed phenomena.

8.6 CONCLUSION

Revisiting the three identified areas underpinning the education of pre-service generalist K-6 teachers, and links to the overall findings, may be represented in the diagram Figure 8.4.

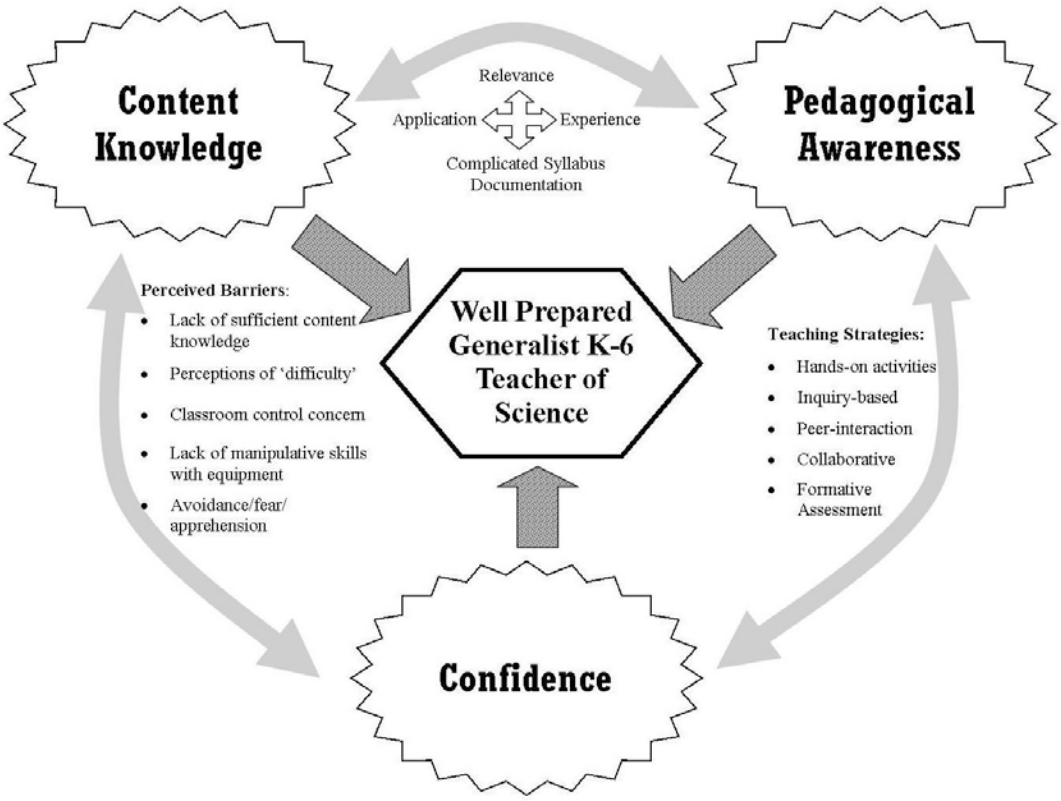

Figure 8.5: Schematic overview of the themes derived from the Phases mapped over the three identified areas underpinning the education of pre-service generalist K-6 teachers framework.

By way of explanation, note the following points:

Content Knowledge: appropriate level of knowledge and understanding of the content and concepts to be taught. Participants indicated that they could not possibly 'learn' all the knowledge required in the limited time available in teacher education courses, and acknowledged they would have to 'learn up on it' prior to teaching aspects of the syllabus mandated content. This perceived lack of knowledge and understanding led to apprehension about their ability to teach the content effectively, negatively impacting on their confidence, and often resulting in avoidance of teaching science, or affording it a minimal treatment.

Pedagogical Awareness: understanding of research supported mechanisms to develop knowledge, understanding and skills in learners. Participants suggested that less time should be spent in their pre-service education science courses trying to 'ingest' large quantities of apparently irrelevant content, and spend more time on learning how, and practising how, to teach science in an exciting, relevant and effective manner.

Confidence: a self-belief that the personally held knowledge and understanding of the content, and pedagogies, will combine to provide meaningful and effective learning experiences for the students entrusted to be taught in their class.

Specifically, the findings of this project confirm previously researched components of learning. These include:

- P-O-E is an effective science learning/teaching strategy; and
- Peer-learning is an effective science learning/teaching strategy.

Information gleaned from this project includes:

- For pre-service teachers, teaching one thing really well builds confidence and develops a suite of pedagogical tools that provides access to a broader investment in the future teaching of science concepts;
- Pre-service teachers respond favourably to the modelling of teaching strategies as part of their pre-service education;
- Learners prefer to explore phenomena and concepts, that are within their sphere of interest, or with which they have had some experience;
- The addition of a 'Share' component to the Predict-Observe-Explain learning/teaching strategy effectively aids in:
    - The construction of desired models of phenomena, as a consequence of peer-interaction, by incorporating socially familiar language;
    - Developing cooperative skills among learners;

  - Enhanced teamwork; and
  - Negotiation of explanations that build upon existing models, or replace ones that do not conform with observation or experience (cognitive dissonance).
- Emphasis on the identification and application of formative assessment strategies that facilitate reflective practise in pre-service K-6 teachers, in terms of:
  - How best to identify existing knowledge;
  - Identifying the effectiveness of the learning experiences and achievement of desired learning outcomes;
  - The construction of remediatory learning experiences should the desired outcomes not be met; and
  - The importance of negotiating additional remedial learning opportunities with the individual learner.
- The linking of formative assessment with additional experiences, in a reiterative process, enhances individual opportunity to achieve the desired level of conceptual understanding.
- The open-ended nature of the rotational reiterative process is suited to differentiated learning, demonstrating that regardless of the preliminary level of the learner's understanding, or entry point to the process, they can still progress.

The iterative nature of the activities encouraged the development, application, and refinement of formative assessment strategies, from the perspective of future K-6 generalist teachers. The application of these strategies also led to an awareness of where the learner was situated in the continuum of desired conceptual understanding: how the learner could be identified as having reached the desired level of understanding, and therefore moved to the next level; or indeed if the learner was having some demonstrated and defined difficulty, and was therefore in need of remediation activities suited to the individual.

8.7 RECOMMENDATIONS, AND DIRECTIONS FOR FUTURE RESEARCH

This project found that focusing on teaching strategies, rather than a content focus on pre-service science teacher education, increased an individuals confidence. The essence of collaboration as an effective learning strategy was also identified as a builder of teacher confidence.

This study primarily utilised hands-on activities to scaffold participants' learning. Future extensions of this research could consider the inclusion of other teaching strategies such as simulations or role-plays into the development of reiterative sequences.

As one participant summarised many expressed opinions:

> *"In the time we have available, you shouldn't try to teach us about everything we are supposed to teach, just teach us how to teach something really well, and we could maybe apply what we learn about teaching to the teaching of other topics."*
>
> (SID P2P2W4GWw117)

In the context of the K-6 science teacher education programs, the identification of the content to be explored could be negotiated with the pre-service teachers, reflecting desired practise in real classrooms in terms of responding to student questions. Future research could evaluate the impact of reducing the covered content, and developing a suite of support materials based on reiterative sequential approaches. Such materials could further develop desirable background understanding of the concepts such as changes in magnetic flux leading to the generation of electric current in conductors. Comparisons between the sequence developed by this research project and others based on similar inquiry based pedagogical approaches such as PET and Physics by Inquiry (see Section 2.3.4)

In relation to the theoretical underpinnings of this study, further investigation into the relationship between the reiterative Predict-Observe-Explain-Share sequences, and the progression of the individual learner's Zone of Proximal Development, may provide a valuable insight into developing effective pedagogy. A key focus within this future research would be in the area of formative assessment. The research team identified the possible value that the application of the SOLO taxonomy, developed by Biggs and Collis (1982), would provide a useful and relevant framework for researchers and pre-service teachers to develop and assess reiterative sequences.

REFERENCES

42 Explore – Electricity (online: http://42explore.com/electric.htm)

AAAS. (1989), *Science for all Americans/Project 2061*, American Association for the Advancement of Science. New York. Oxford University Press.

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, D., and Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education.* vol. 88. pp. 397–419.

Abell, S. and Roth, M. (1991). Coping with constraints of teaching elementary science: A case study of a science enthusiast student teacher. *Science Education.* vol. 76. no. 6. pp. 581–595.

Adey, P., Shayer, M. and Yates, C. (1989). Cognitive acceleration: the effects of two years of intervention in science classes. In P. Adey, J. Bliss, J. Head and M. Shayer (Eds.) *Adolescent Development and School Science*. London. Falmer Press. pp. 240–257.

Aikenhead, G. (2000). Renegotiating the culture of school science. In R. Millar, J. Leach, & J. Osborne (Eds.). *Improving Science Education: The Contribution of Research*. pp. 245-264. Birmingham UK. Open University Press.

Ainley, J., Kos, J. and Nicholas, M. (2008). Participation in Science, Mathematics and Technology in Australian Education. *ACER Research Monograph* No 63. Canberra. ACER.

Akerson, V. (2005). How do Elementary Teachers Compensate for Incomplete Science Content Knowledge? *Research in Science Education*. vol. 35. pp. 245-268

Akerson, V. and Flanigan, J. (2000). Preparing preservice teachers to use an interdisciplinary approach to science and language arts instruction. *Journal of Science Teacher Education*. vol. 11. no. 4. pp. 345-362.

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy: Project 2061*. New York, NY. Oxford University Press.

Anderson, L.W., and Krathwohl, D. (Eds.). (2001). *A Taxonomy for Learning, Teaching and Assessing: a Revision of Bloom's Taxonomy of Educational Objectives.* New York. Longman.

Anderson, R. and Helms, J. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching.* vol. 38. pp. 3-16.

Anderson, R. and Mitchener, C. (1994). Research on science teacher education. In D. L. Gabel (Ed.). *Handbook of research on science teaching and learning.* pp. 3-44. New York. Macmillan.

Angus, M., Olney, H. and Ainley, J. (2007). *In the balance: The future of Australia's primary schools*. Canberra. Australian Primary Principals Association.

Appleton, K. (1977). Is there a fairy godmother in the house? *Australian Science Teachers Journal.* vol. 23. no. 3. pp. 37–42.

Appleton, K. (1995). Student teachers' confidence to teach science: Is more science knowledge necessary to improve self-confidence? *International Journal of Science Education.* vol. 19. pp. 357–369.

Appleton, K. (2002). Science Activities That Work: Perceptions of Primary School Teachers. *Research in Science Education.* vol. 32. pp. 393-410.

Appleton, K. (2003). How Do Beginning Primary School Teachers Cope with Science? Toward an Understanding of Science Teaching Practice. *Research in Science Education.* vol. 33. pp. 1–25.

Appleton, K. and Asoko, H. (1996). A case study of a teacher's progress towards using a constructivist view of learning to inform teaching in elementary science. *Science Education*. vol. 80. no. 2. pp. 165-180.

Argonne National Laboratory: (online: http://www.newton.dep.anl.gov/askasci/phy05/phy05305.htm)

Arrow, K. and Capron, W. (1959). Dynamic shortages and price rises: The Engineer-Scientist Case. *The Quarterly Journal of Economics*. vol. 73. no. 2. pp. 292-308.

Asoko, H. Welford, G., Osborne, J. and Scott, P. (Eds.) (1996). *Developing scientific concepts in the primary classroom: Teaching about electric circuits*. Research in science education in Europe: Current issues and themes. London. Falmer Press. pp. 36-49.

Atkinson, R. (1990). Supply and Demand for Scientists and Engineers: A National Crisis in the Making. *Science*. vol. 248. pp. 425-432. Retrieved 22 April 2009 from http://mysite.verizon.net/vze2sk2i/spn/spn1to12/spnrefs/atkinphdshort.pdf.

Australian Academy of Science. (2005). *Primary connections: Linking science with literacy.* Retrieved 15 September 2009 from http://www.science.org.au/primaryconnections/index.htm

Australian Academy of Science. (2007). *Primary Connections,* Australian Academy of Science, Canberra. Retrieved 3 April 2008 from http://www.science.org.au/primaryconnections/Intro%20to%20PC.pdf

Australian College of Education. (2001). *A National Declaration for Education 2001*. Unicorn. vol. 27. no. 2. pp. 3–26.

Australian Curriculum, Assessment & Reporting Authority. (ACARA). (2010). The Australian Curriculum: Science. Draft consultation version 1.0.1. Retrieved 11 April, 2010 from http://www.australiancurriculum.edu.au/Home

Australian Department of Education, Science and Training (DEST) Committee for the review of teaching and teacher education. (2003). *Australia's teachers: Australia's future. Advancing innovation, science, technology and mathematics.* Canberra: DEST. Commonwealth of Australia.

Australian Education Union (AEU). (2009). *New Educators Survey 2008*. Melbourne. Retrieved 11 February 2009 from www.aeufederal.org.au/Publications/2009/Nesurvey08res.pdf

Azaiza, I., Bar, V. and Galili, I. (2006). Learning Electricity in Elementary School. *International Journal of Science and Mathematics Education*. vol. 4. pp. 45–71

Bacon, R. (1994). The Teaching and Learning (TLT) Programme. *Computers in Physics Education*. vol. 2. no. 5.

Beaty, W. (2001). *"Electricity" Misconceptions in K-6 Textbooks*. Retrieved 16 August 2009 from http://www.eskimo.com/~billb/miscon/eleca/html#exist

Beaty, W. (2005). *"Static Electricity" Misconceptions*. Retrieved 12 September 2010, from http://amasci.com/emotor/stmiscon.html

Biggs, J. and Collis, K. (1982). *Evaluating the Quality of Learning: The SOLO Taxonomy*. New York. Academic Press.

Biggs, J. *Solo Taxonomy*. Online. Retrieved 16 June 2010 from http://www.johnbiggs.com.au/solo_graph.html

Bitner, B. (1992). *Preservice Elementary and Secondary Science Methods Teachers: Comparison of Formal Reasoning, Act Science, Process Skills and Physical Science Misconception Scores*. Boston. National Association for the Research in Science Teaching.

Black, P. (1993). Formative and Summative Assessment by Teachers. *Studies in Science Education*. vol. 21. pp. 49-97.

Bloom, B.S. (Ed.) (1956-1964). *Taxonomy of Educational Objectives*. New York. David McKay Company Inc.

Bloom, L. R. (1998). *Under the sign of hope: feminist methodology and narrative interpretation*. New York. State University of New York Press.

Blosser, P. (1987). Science Misconceptions Research and Some Implications for the Teaching of Science to Elementary School Students. ERIC/SMEAC *Science Education Digest*. no. 1. Retrieved 1 March 2009 from http://www.ericdigests.org/pre-925/science.htm

Board of Studies New South Wales (BoS NSW). (1993). *Science and Technology K-6*: *Syllabus and Support Document*. Retrieved 4 March 2010 from http://k6.boardofstudies.nsw.edu.au/files/science-and-technology/k6_scitechsyll.pdf

Board of Studies New South Wales. (BoS NSW). (2010). *NSW Primary Curriculum Foundation Statements*. Retrieved 4 March 2010 from http://k6.boardofstudies.nsw.edu.au/go/k-6-curriculum/foundation-statements

Bonk, C. and Cunningham, D. (1998). Searching for learner-centered, constructivist, and sociocultural components of collaborative educational learning tools. In C. J. Bonk, & K. S. King (Eds.). *Electronic collaborators: Learner-centered technologies for literacy, apprenticeship, and discourse*. Mahwah, NJ. Lawrence Erlbaum Associates. pp. 25-50.

Borges, A. (1999). Mental models of electricity. *International Journal of Science Education*. vol. 21. no. 1. pp. 95-117.

Borges, A. and Gilbert, J. (1998). Models of magnetism, *International Journal of Science Education*. vol. 20. no. 3. pp. 361-378.

Borges, T. and Gilbert, J. (1999). Mental models of electricity. *International Journal of Science Education*. vol. 21. no. 1. pp. 95–117.

Boud, D., Cohen, R. and Sampson, J. (2001). Peer learning in higher education: Learning from and with each other. London. Kogan Press.

Bowden, J., Dall'Alba, G., Laurillard, D. Martin, E., Marton, F., Masters, G., Stephanou, A. and Walsh, E. (1992). Displacement, velocity and frames of reference: Phenomenographic studies of students' understanding and some implications for teaching. *American Journal of Physics*. vol. 60. pp. 262-269.

Bracey, G. (2008). On the Shortage of Scientists and Engineers. *The Phi Delta Kappan*. vol. 89. no. 7. pp. 536-538. Retrieved 23 June 2009 from http://www.jstor.org/stable/20442555

Bradamante, F, Michelini, M. and Stefanel, A. (2006). Learning Problems Related to the Concept of Field. In B.G. Sidharth, F. Honsell and A. de Angelis (Eds.) *Frontiers of Fundamental Physics.* Netherlands. Springer. pp. 367-379.

Brousseau, G. (1992). Didactique: What can it do for the teacher? In R.Doudy and A Mercier (Eds.). *Research in Didactique of Mathematics.* Paris. La Pensée Sauvage. pp. 7-19.

Brown, A. (1992). Design experiment: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences.* vol. 2. pp. 141-178.

Brown, K. and Jackson, D. (2007). Simple Experiments to Help Students Understand Magnetic Phenomena. *The Physics Teacher*. vol. 45. pp. 425-429

Bruner, J. (1961). The Art of Discovery. *Harvard Educational Review.* vol. 31. pp. 21-32.

Bruner, J. (1966). *Toward a theory of instruction*. New York. W.W. Norton & Co.

Bruner, J. (1990). *Acts of Meaning*. Cambridge. Harvard University Press.

Burrell, G. and Morgan, G. (1979). *Sociological Paradigms and Organisational Analysis.* London. Heinemann Educational Books.

Byard, R., Hanson, K., Gilbert, J., James, R., Nadeau, J., Blackborne, B. and Krous, H. (2003). Death due to electrocution in childhood and early adolescence. *Journal of Paediatric Child Health.* vol. 39. no. 1. pp. 46-48.

Bybee, R. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth. Heinemann.

Bybee, R. (2006). *Science teaching in the 21st Century: Five themes for educational leaders.* A presentation for Science Education Leaders, New York City Schools and American Museum of Natural History. New York. BSCS.

Campbell, D. and Fiske, D. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin.* vol. 56. no. 2. pp. 81-105.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge. MIT Press.

Carey, S. (1991). Knowledge acquisition: Enrichment or conceptual change? In S. Carey & R. Gelman (Eds.). *The epigenesis of mind*. Hillsdale, NJ. Lawrence Erlbaum Associates. pp. 257-291.

Carmichael, P., Driver, R., Holding, B, Phillips, I, Twigger, D. and Watts, M. (1990). *Research on Students' Conceptions in Science: A Bibliography*. Children's Learning in Science Research Group, Centre for Studies in Science and Mathematics Education, University of Leeds.

Chabay, R. and Sherwood, B. (1999). *A unified treatment of electrostatics and circuits.* Retrieved 12 August 2010, from http://www.matterandinteractions.org/Content/Articles/circuit.pdf

Chabay, R. and Sherwood, B. (2005). *Brief Electricity and Magnetism Assessment*. Retrieved 12 August 2010, from http://www.compadre.org/Repository/document/ServeFile.cfm?ID=3775&DocID=111

Champagne, A., Gunstone, R. and Klopfer, L. (1985). Effecting changes in cognitive structures among physical students. In West, L. and Pines, L. (Eds.) *Cognitive structure and conceptual change*. Orlando. Academic Press.

Champagne, A., Klopfer, L. and Anderson, I. (1980). Factors Influencing the Learning of Classical Mechanics. *American Journal of Physics.* vol. 48. p. 1074

Chan, C., Burtis, J. and Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction.* vol. 15. pp. 1–4

Chi, M. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. N. Giere (Ed.), *Cognitive models of science: vol. 15. Minnesota studies in the philosophy of science*. Minneapolis. University of Minnesota Press. pp. 129-186

Chi, M. and Roscoe, R. (2002). The Processes and Challenges of Conceptual Change. In Limon M. and Mason L. (Eds.). *Reconsidering Conceptual Change. Issues in Theory and Practice* pp. 3-29. Dordrecht. Kluwer Academic Publishers.

Churches, A. (2008). Bloom's Digital Taxonomy. Retrieved 6 June 2009 from www.scribd.com/doc/8000050/Blooms-Digital-Taxonomy-v212

Clarke, B. and Feltham, W. (1990). Facilitating peer group teaching within nurse education. Nurse Education Today. vol. 10. pp. 54–57.

Clement, J. (2000). Model Based Learning as a Key Research Area for Science Education. *International Journal of Science Education*. vol. 22. no. 9. pp. 1041-1053.

Cobb, P. (1994). Where Is the Mind? Constructivist and Sociocultural Perspectives on Mathematical Development. *Educational Researcher.* vol. 23. no. 7. pp. 13-20.

Cobb, P. (1996). Constructivism and learning. In E. De Corte and F. E Weinert. (Eds.) *International Encyclopaedia of Developmental and Instructional Psychology.* Pergamon Press. pp. 338-341.

Cohen, L. and Manion, L. (1994). *Research Methods in Education 4th Edn.* London. Routledge.

Cohen, L., Manion, L. and Morrison, K. (2007). *Research Methods in Education. 6th Edn.* London. Routledge.

Colaizzi, P. (1978). Psychological research as the phenomenologist views it. In R.S. Valle and M. King. (Eds.) *Existential Phenomenological Alternatives for Psychology.* New York. Oxford University Press.

Coleman, J. S. (1958). Relational Analysis: The Study of Social Organization with Survey Methods. *Human Organization.* vol. 17. pp. 28-36.

Coll, R., France, B. and Taylor, I. (2005). The Role of Models/and Analogies in Science Education: Implications from Research. *International Journal of Science Education*, vol. 27. no. 2. pp. 183-198.

Collins, S., Osborne, J., Ratcliffe, M., Millar, R. and Duschl, R. (2001). *What 'ideas about science' should be taught in school science? A Delphi study of the expert community*. Paper presented at the Annual Conference of the American Educational Research Association. Seattle.

Commonwealth of Australia. (2009). *Shape of the Australian Curriculum: Science*. National Curriculum Board. Retrieved 22 March 2010 from http://www.acara.edu.au/verve/_resources/Australian_Curriculum_-_Science.pdf

Community Learning Network – Electricity Concepts. Retrieved 22 May 2010 from http://www.cln.org/themes/electricity.html

Community Learning Network – Magnetism Concepts. Retrieved 22 May 2010 from http://www.cln.org/themes/magnetism.html

Cornish, D. and Dukette, D. (2009). *The Essential 20: Twenty Components of an Excellent Health Care Team.* Pittsburgh. Rose Dog Books. pp. 72-73.

Cosgrove, M .(1995). A study of science – in – the –making as students generate an analogy for electricity. *International Journal of Science Education*. vol. 17. pp. 295 – 310.

Cosgrove, M., and Osborne, R. (1985). A teaching sequence on electric current. In R. Osborne & P. S. Freyberg (Eds.), *Learning in science: The implications of childrens' science.* Auckland. Heinemann. pp. 112-123.

Cosgrove, M. (1995). A study of science – in – the –making as students generate an analogy for electricity. *International Journal of Science Education*. vol. 17. pp. 295 – 310.

Crotty, M. (1998). *The Foundations of Social Research.* London: Sage.

Crouch, C. and Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics*. vol. 69. no. 9. pp. 970-977.

Dave, R. (1970). Psychomotor levels. In R. J. Armstrong (Ed.). *Developing and writing behavioral objectives.* Tucson, Arizona. Educational Innovators Press.

Davis, E. and Smithey, J. (2009). Beginning Teachers Moving Toward Effective Elementary Science Teaching. *Science Education.* vol. 93. no. 4. pp. 745-770

Dekkers, J., and De Laeter, J. (1997). The changing nature of upper secondary school science subject enrolments. *Australian Science Teachers' Journal.* vol. 43. no. 4. pp. 35-41.

Dekkers, J., and DeLaeter, J. (2001). Enrolment trends in school science education in Australia. *International Journal of Science Education.* vol. 23. no. 5. pp. 487-500.

Demirci, N., and Çirkinoglu, A. (2004). Determining Students' Preconceptions/Misconceptions in Electricity and Magnetism. *Journal of Turkish Science Education.* vol. 1. no. 2. pp. 51–54.

Denzin, N. (1978). The Research Act: A Theoretical Introduction to Sociological Methods. Engelwood Cliffs. Prentice Hall.

Department of Employment, Education, and Training. (DEET). (1989). *Discipline review of teacher education in mathematics and science*. Canberra, ACT. Australian Government Publishing Service.

DEST. Committee for the review of teaching and teacher education. (2003). '*Australia's teachers: Australia's future. Advancing innovation, science, technology and mathematics*'. Commonwealth of Australia. Canberra. Australian Department of Education, Science and Training.

Dickinson, V. and Flick, L. (1996). How to succeed in physics without really crying. *Science and Children.* vol. 33. no. 8. pp. 37-38.

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction.* vol. 10. no. 2. pp. 105-225.

Dougiamas, M. (1998). A Journey into Constructivism. Retrieved 28 March 2010 from http://dougiamas.com/writing/constructivism.html

Dowling, M. (2007). From Husserl to van Manen. A review of different phenomenological approaches. *International Journal of Nursing Studies.* vol. 44. no. 1. pp. 131-142.

Dreyfus, A., Jungwirth, E. and Eliovitch, R. (1990). Applying the "cognitive conflict" strategy for conceptual change—some implications, difficulties and problems. *Science Education*. vol. 74. pp. 555–569

Driver, R. and Easley, J. (1978). Pupils and Paradigms: A Review of Literature Related to Concept Development in Adolescent Science Students. *Studies in Science Education.* vol. 10. pp. 37–70.

Driver, R., Asoka, H., Leach, J., Mortimer, E., and Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*. vol. 23. pp. 5–12.

Driver, R., Guesne, E. and Tiberghien, A. (Eds.). (1983). *Children's Ideas in Science*. Milton Keynes. UK. Open University Press.

Driver, R., Squires, A., Rushworth, P. and Wood-Robinson, V. (1994). *Making sense of secondary science*. New York. Routledge.

Driver,R. (1989). The construction of scientific knowledge in school classrooms. In Millar, R. (Ed.). *Doing science: Images of science in science education*. New York. Falmer Press. pp. 83–106

Driver. R. (1983). *The Pupil as Scientist?* Milton Keynes. Open University Press.

Duit, R. (1991). On the Role of Analogies and Metaphors in Learning Science. *Science Education.* vol. 75. no. 6. pp. 649-672.

Duit, R. (1996). The Constructivist View in Science Education. What it Has to Offer and What Should not be Expected From It. *Investigações em Ensino de Ciências.* vol. 1. pp. 40–75.

Duit, R. and von Rhöneck, C. (1997). Learning and understanding key concepts of electricity. In A. Tiberghien, E. Jossem, & J. Barojas (Eds.). *Connecting research in physics education with teacher education*. International Commission on Physics Education. Retrieved 3 July 2009 from http://www.physics.ohio-state.edu/jossem/ICPE/C2.html

Duit, R., Goldberg, F., and Niedderer, H. (Eds.) (1991). *Research in physics learning: Theoretical issues and empirical studies*. Institute for Science Education at the University of Keil.

Duit, R., Jung, W. and von Rhöneck, C. (1985). (Eds.). *Aspects of understanding electricity. Proceedings of an International Workshop*. Kiel Wester. Germany. Ludwigsburn.

Duit, R., Roth, W., Kormorek, M. and Wilbers, J. (2001). Fostering Conceptual Change by Analogies – Between Scylla and Charybdis. *Learning and Instruction*. vol. 11. pp 283-304

Duschl, R., Schweingruber, H. and Shouse, A. (Eds.). (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8*. Committee on Science Learning, Kindergarten through Eighth Grade. National Academies Press. Retrieved 14 October 2009 from http://www.nap.edu/catalog/11625.html

Eltis, K. (Chair). (1995). *Focusing on learning: Report of the Review of Outcomes and Profiles in New South Wales Schooling*. Sydney. NSW Government.

Engelhardt, P., Corpuz, E. Ozimek, D. and Rebello, N. (2004). The Teaching Experiment – What it is and what it isn't. *2003 Physics Education Conference. AIP Conference Proceedings*. pp. 157-160.

Eltis, K. and Crump, S., (2003). *Time to Teach, Time to Learn: Report on the Evaluation of Outcomes Assessment and Reporting in NSW Government Schools.* Sydney. NSW Department of School Education.

Epni, S., and Keles, E. (2006). Turkish Students' Conceptions about Simple Electric Circuits. *International Journal of Science and Mathematics Education*. vol. 4. pp. 269–291.

Erickson, G. (1994). Pupils' understanding of magnetism in a practical assessment context: The relationship between content, process and progression. In P. Fensham, R. Gunstone and R. White (Eds.). *The Content of Science: A Constructivist Approach to its Teaching and Learning*, Falmer Press. London. Pp. 80-97.

Ernst, H. and Colthorpe, K. (2007). The efficacy of interactive lecturing for students with diverse science Backgrounds. *Advances in Physiology Education.* vol. 31. pp. 41-44.

Evans, D., Gray G., Krause, S., Martin, J., Midkiff, C., Notaros, B., Pavelich, M., Rancour, D., Reed-Rhoads, T., Steif, P., Streveler, R. and Wage, K. (2003). Progress on concept inventory assessment tools. Proceedings of the 2003 FIE Conference. Frontiers in Education. Retrieved 16 July 2009 from http://fie-conference.org/fie2003/index.htm

Evans, R. and Rennie, L. (2009). Promoting understanding of, and teaching about, scientific literacy in primary schools. *Teaching Science*. vol. 55. no. 2. pp25-30.

Explainthatstuff – magnetism. Retrieved 22 May 2010 from http://www.explainthatstuff.com/magnetism.html

Fensham, P. (1985). Science for all: a reflective essay. *Journal of Curriculum Studies*. vol. 17. no. 4. pp. 415–435.

Fensham, P. (2007). Context or Culture: Can TIMSS and PISA Teach us about what Determines Educational Achievement in Science? In Atweh, B. *et al*., *Internationalisation and globalisation in mathematics and science education*. Dordrecht. Springer.

Ferguson-Hessler, M. and de Jong, T. (1987). On the quality of knowledge in the field of electricity and magnetism. *Am. J. Phys*. vol. 55. no. 492.

Finkelstein, N. (2010). *Strengthening Undergraduate and Graduate STEM Education*. Research and Science Education Subcommittee, Committee on Science and Technology, U.S House of Representatives. Retrieved 2 July 2010 from http://science.house.gov/hearing/subcommittee-research-and-science-education-hearing-strengthening-stem-education

Finkelstein, N., Perkins, K., Adams, W., Kohl, P. and Podolefsky, N. (2004). *Can Computer Simulations Replace Real Equipment in Undergraduate Laboratories*? Paper presented at Physics Education Research Conference 2004, Sacramento, California. Retrieved 2 February 2010 from http://dx.doi.org/10.1063/1.2084711

Fox, R. (2001). Constructivism Examined. *Oxford Review of Education.* vol. 27. no. 1. pp. 23-35.

Furio, C. and Guisasola, J. (1998). Difficulties in Learning the Concept of Electric Field. *Science Education*. vol. 82. no. 4. pp. 511-526.

Gallimore, R. and Tharp, R. (1990). Teaching mind in society. In L. Moll (Ed.) *Vygotsky and education: Instructional implications and social applications of sociohistorical psychology*. New York. Cambridge University Press.

Gil-Pérez, D, Guisasola, J., Moreno, A., Cachapuz, A., Pesssoa de Carvalho, A., Martinez Torregrosa, J., Salinas, J., Valdes, P., Gonzalez, E., Gene Duch, A., Dumas-Carre, A., Tricarico, H. and Gallego, R. (2002). Defending Constructivism in Science Education. *Science & Education.* vol. 11. pp. 557–571.

Gilbert, J. and Watts. D. (1983). Concepts, Misconceptions and Alternative Conceptions: Changing Perspectives in Science Education. *Studies in Science Education.* vol. 10. no. 1.

Gilbert, K. (1994). The development of educational research in the physical sciences in some European countries. In H. J. Schmidt (Ed.). *Problem Solving and Misconceptions in Chemistry and Physics.* Dortmund. International Council of Associations for Science Education. pp. 15–28.

Ginns, I. and Watters, J. (1998). Beginning elementary school teachers and the effective teaching of science. *Journal of Science Teacher Education*. vol. 10. no. 4. pp. 287-313.

Giorgi, A., Fischer, W. and Von Eckartsberg, R. (Eds.) (1971). *Duquesne Studies in Phenomenological Psychology.* vol. 1. Pittsburgh. Duquesne University Press.

Gizmos: Retrieved 22 May 2010 from http://www.explorelearning.com/index.cfm?method=cResource.dspResourceCatalog

Glynn, S. (2008). *Making science concepts meaningful to students: teaching with analogies.* Retrieved 19 November 2010 from http://www.coe.uga.edu/twa/PDF/Glynn2008MakingScienceConceptsMeaningful.pdf

Goodman, L. (1961). Snowball sampling. *Annals of Mathematical Statistics.* vol. 32. no. 1. pp. 148–170.

Goodrum, D., Hackling, M. and Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools*. Canberra. Commonwealth of Australia.

Goodrum, D. and Rennie, L. (2007). *The National Action Plan. Australian School Science Education National Action Plan, 2008-2012*. Volume 1. Australian Government Department of Education, Science and Training. Retrieved 12 June 2009 from http://eric.ed.gov/PDFS/ED511041.pdf

Gordon Speer: Electricity and Magnetism. Retrieved 22 May 2010 from http://www.essex1.com/people/speer/elect.html

Gunstone, R. and White, R. (1981). Understanding Gravity. *Science Education.* vol. 65. pp. 291-299

Hackling, M., (2002). Assessment of Primary Students Scientific Literacy. *Investigating.* vol. 18. no 3.

Hackling, M. (2007). *Primary Connections: Stage 2 research report*. Canberra. Australian Academy of Science.

Hackling, M. and Prain, V. (2005). *Primary Connections: Stage 2 research report*. Canberra. Australian Academy of Science.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics.* vol. 66. no. 1. pp. 64-74.

Hake, R. (2002). *Physics first: Opening battle in the war on science/math illiteracy?* Unpublished manuscript. Retrieved 22 April 2009 from http://www.physics.indiana.edu/~hake/PhysFirst-AJP-6.pdf

Hake R. (2007). Six Lessons From The Physics Education Reform Effort. *Latin American Journal of Physics Education.* vol. 1. no. 1. p. 25. Retrieved 2 September 2009 from http://www.journal.lapen.org.mx.

Halloun, I., and Hestenes, D. (1985). The Initial Knowledge State of College Physics Students. *American Journal of Physics*. vol. 53. no. 11. pp. 1043–1055

Hammer, D. and Elby, A. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.). *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah. Erlbaum. pp. 169-190.

Hammer, D., Elby, A., Scherr, R. and Redish, E. (2005). Resources, framing, and transfer. In J. Mestre (Ed.) *Transfer of learning from a modern multidisciplinary perspective.* Greenwich. Information Age Publishing. pp. 89-120.

Hancock, C. (1940). An Evaluation of Certain Popular Science Misconceptions. *Science Education*. vol. 24. pp. 208-213.

Hargreaves, A., Earl, L., Moore, S., and Manning, S. (2001). *Learning to change: Teaching beyond subjects and standards*. San Francisco. Jossey Bass.

Harlen, W. (1997). *The teaching of science in primary schools*. London. David Fulton.

Harlen, W. and Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. *International Journal of Science Education*. vol. 19. pp. 93-105.

Heywood, D. (2002). The Place of Analogies in Science Education. *Cambridge Journal of Education*. vol. 32. no. 2. pp. 233-247.

Holloway, I. (1997). *Basic Concepts for Qualitative Research.* Oxford. Blackwell Science. pp. 116-120.

Hooley, N. (2008). *Teacher Education as Democratic Public Sphere*. Australian Association for Educational Research. Retrieved 5 May 2009 from http://www.aare.edu.au/aer/online/0803_d.pdf

Internet4Classrooms – Electricity for Elementary Science. Retrieved 22 May 2010 from http://www.internet4classrooms.com/science_elem_electricity.htm

Jenkins, E. (2000). Constructivism in School Science Education: Powerful Model or the Most Dangerous Intellectual Tendency? *Science & Education*. vol. 9. pp. 599–610.

Jenkins, E. (2002). A New Science Curriculum For All? In Mayer, V. (Ed.). *Global Science Literacy*. Netherlands. Kluwer Academic Publishers.

Johnson, A. (1999). *Students' Development of Models of Magnetic Materials, Patterns of Group Activity, and Social Norms in a Physics Classroom*. Unpublished PhD in Science Education dissertation, University of California, San Diego

Johnson, B. (1997). Examining the validity structure of qualitative research. *Education.* vol. 118. no. 3. pp. 282-292.

Johnson, D. and Johnson, R. (1979). Conflict in the Classroom: Controversy and Learning. *Review of Educational Research*. vol. 49. no. 1. pp. 51-70.

Johnson, D. and Johnson, R. (2009). Energizing Learning: The Instructional Power of Conflict. *Educational Researcher*. vol. 38. no. 1. pp. 37-51.

Johnson, D., Johnson, R. and Smith, K. (1991). *Active Learning: Cooperation in the College Classroom*. Edina, MN. Interaction Book Company.

Jolly, P. (2010). ICPE Chair's Corner. *International Newsletter on Physics Education.* vol. 59. pp.1-9.

Kagan, D. (1990). Ways of Evaluating Teacher Cognition: Inferences Concerning the Goldilocks Principle. *Review of Educational Research*. vol. 60. no. 3. pp. 419-469.

Kang, N. (2007). Elementary Teachers' Epistemological and Ontological Understanding of Teaching for Conceptual Learning. *Journal of Research in Science Teaching.* vol. 44. no. 4. pp. 1292–1317.

Kaplan, A. (1964). The conduct of inquiry: methodology for behavioral science. San Francisco. Chandler.

Kelly, J. (2000). Rethinking the elementary science methods course: A case for content, pedagogy, and informal science education. *International Journal of Science Education*. vol. 22. pp. 755-777.

Keys, C., and Bryan, L. (2001). Co-Constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching*. vol. 38. no. 6. pp. 631–645.

Kitchenham, B. and Pfleeger, S. (2002). Principles of Survey Research. *Software Engineering Notes.* vol. 27. nos. 1-5.

Koch, T. and Harrington, A. (1998). Reconceptualizing rigor: the case for reflexivity. *Journal of Advanced Nursing.* vol. 28, no. 4. pp. 882-890.

Kolb, D. (1984). *Experiential learning: experience as the source of learning and development.* New Jersey: Prentice Hall.

Komorek, M. and Duit, R. (2004). The teaching experiment as a powerful method to develop and evaluate teaching and learning sequences in the domain of non-linear systems. *International Journal of Science Education*. vol. 26. no. 5. Pp. 619 — 633

Krathwohl, D., Bloom, B. and Masia, B. (1964/1999). *Taxonomy of educational objectives: Handbook II: Affective domain*. New York. David McKay Co.

Kuenzi, J., Mathews, C., and Mangan, B. (2006). *Science, Technology, Engineering, and Mathematics (STEM) Education Issues and Legislative Options*. Washington, DC. Congressional Research Service, The Library of Congress.

Kvale, S. (1996). *Interviews: An Introduction to Qualitative Research Interviewing*. Thousand Oaks. Sage Publications.

Laidlaw, K., Taylor, N. and Fletcher, P. (2009). Teaching Primary Science in Rural and Regional Australia: Some Challenges Facing Practicing and Pre-service Teachers. *Journal of Science and Mathematics Education in Southeast Asia.* vol. 32. no. 2. pp. 105-130.

Lawrenz, F. (1986). Misconceptions of Physical Science Concepts among Elementary School Teachers. *School Science and Mathematics*. vol. 86. pp. 654-660

Leach, J. (1999). Students' understanding of the co-ordination of theory and evidence in science. *International Journal of Science Education*. vol. 21. no. 8. pp. 789–806.

Leach J. and Scott P. (2002) Designing and evaluating science teaching sequences: An approach drawing upon the Concept of Learning Demand and a Social Constructivist Perspective on Learning. *Studies in Science Education*. vol. 38. p. 115

Learn NC: Online Teacher Education Program. Retrieved 16 September 2009 from http://www.learnnc.org/lp/pages/6998

Lee, G., Kwon, J., Park, S.-S., Kim, J.-W., Kwon, H.-G. and Park, H.-K. (2003). Development of an instrument for measuring cognitive conflict in secondary-level science classes. *Journal of Research in Science Teaching*. vol. 40. pp.585–603.

Lijnse, P. (1997). Curriculum Development in Physics Education. In Andrée Tiberghien, E. Leonard Jossem, and Jorge Barojas, (Eds.) *Connecting Research in Physics Education with Teacher Education.* International Commission on Physics Education.

Limón, M. (2001). On the Cognitive Conflict as an Instructional Strategy for Conceptual Change: A Critical Appraisal. *Learning and Instruction*. vol. 11. no. 4. pp. 357-380.

Limón, M. and Carretero, M. (1997). Conceptual change and anomalous data: A case study in the domain of natural sciences. *European Journal of Psychology of Education*. vol. 12. no. 2. pp. 213–230

Lin, N. (1976). *Foundations of Social Research.* New York. McGraw-Hill.

Lindahl, B. (2001). Reasons for choosing or not choosing science for upper secondary school. About pupils' attitudes towards and understanding of science. In R. Evans, A. Møller Andersen & H. Sørensen (Eds.). *Bridging Research Methodology and Research Aims*. Proceedings from The Fifth European Science Education Summerschool at Gilleleje, Denmark. September 6-13, 2000.

Littledyke, M. and Huxford, L. (Eds.) (1998). *Teaching the Primary Curriculum for Constructive Learning.* London. David Fulton.

Littledyke, M. and Manolas, E. (2010). Ideology, epistemology and pedagogy: barriers and drivers to education for sustainability. *Journal of Baltic Science Education.* vol. 9. no 4. pp. 285-302.

Liu, C. and Matthews, R. (2005). Vygotsky's philosophy: Constructivism and its criticisms examined. *International Education Journal.* vol. 6. no. 3. pp. 386-399

Longaretti, L., Godinho, S., Parr, G. and Wilson, J. (2002).Rethinking Peer Teaching. *The Australian Educational Researcher*. Retrieved 22nd September 2010 from http://www.aare.edu.au/02pap/lon02122.htm

Loughran, J. (2007). Science teacher as learner. In S. K. Abell & N. G. Lederman (Eds.). *Handbook of research on science education*. Mahwah. Lawrence Erlbaum Associates.

Lyons, T. (2005). Different Countries, Same Science Classes: Students’ Experiences of School Science in Their Own Words. *International Journal of Science Education*. vol. 28. no. 6. pp. 591-613.

Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education*. vol. 36. no. 3. pp. 285–311.

Lyons, T. (2008). Fundamental Science Concept Score. Course Material EDSE213 UNE. Personal Correspondence May 2009.

Lyons, T. and Quinn, F. (2010). *Choosing Science: Understanding the declines in senior high school science enrolments*. Research Report to the Australian Science Teachers Association. UNE. Retrieved 22 March 2010 from http://www.une.edu.au/simerr/pages/projects/131choosingscience.pdf

Magnet Man. Retrieved 22 May 2010 from http://www.coolmagnetman.com/magreview.htm

Maloney, D., O'Kuma, T., Hieggelke, C., and Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics*. vol. 69. no. 7. pp. 12-19

Marton, F. (1981). Phenomenography - describing conceptions of the world around us. *Instructional Science.* vol. 10. pp. 177-200.

Marton, F. (1986). Phenomenography - a research approach to investigating different understandings of reality. *Journal of Thought.* vol. 21. no. 3. pp. 28-49.

Marton, F. (1989). Phenomenography – A Research Approach to Investigating Different Understandings of Reality. *Journal of Thought.* vol. 21. no. 3. pp. 29-39.

Masters, G. (2005). International Achievement Studies: Lessons From PISA and TIMSS. Research Developments. vol. 13. pp. 6-10.

Masters, G. (2009). *A Shared Challenge: Improving Literacy, Numeracy and Science Learning in Queensland Primary Schools.* Canberra. ACER.

Mather, M. (2006) *Is there a U.S. Shortage of Scientists and Engineers?* Population Reference Bureau. Retrieved 16 April 2009 from http://www.prb.org/Articles/2006/IsThereaUSShortageofScientistsandEngineersItDependsWhereYouLive.aspx

Mathison, S. (1988). Why Triangulate. *Educational Researcher.* vol. 17. no. 2. pp. 13-17

Matthews, G. (1998). *The philosophy of childhood.* Cambridge. Harvard University Press.

Mazur, E. (1997). *Peer Instruction: A User's Manual.* Upper Saddle River, NJ. Prentice-Hall.

McDermott, L., Heron, P. and Shaffer, S. (2005). Physics by Inquiry: A research-based approach to preparing K-12 teachers of physics and physical science. *Forum on Education: American Physical Society Newsletter*. Retrieved 22 July 2010 from http://www.aps.org/units/fed/newsletters/summer2005/mcd2.html

McDermott, L. and Shaffer, P. (1993). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *Am. J. Phys*. vol. 60. no. 994 (1992); Erratum: *Am. J. Phys*. vol. 61. no. 81.

McDermott, L., Shaffer, P. and Constantinou, C. (2000). 'Preparing teachers to teach physics and physical science by inquiry'. *Physics Education.* vol. 35. no. 6. pp. 411-417

MCEETYA. (2003). *Demand and Supply of Primary and Secondary School Teachers in Australia*. Ministerial Council on Education, Employment, Training and Youth Affairs. Retrieved 1 October 2009 from http://www.curriculum.edu.au/verve/_resources/-DAS_teachers-PartsA-D.pdf

MCEETYA. (2005). *Demand and Supply of Primary and Secondary School Teachers in Australia.* Ministerial Council on Education, Employment, Training and Youth Affairs. Retrieved 11 October 2009 from http://www.mceetya.edu.au/public/

McPhan, G. (2008). Generalizing levels of students' understandings about conductivity: a SOLO analysis. *Teaching Science*. vol. 54. no. 2.

Mellado, V., Blanco, L. and Ruiz, C. (1998). A framework for learning to teach science in initial primary teacher education. *Journal of Science Teacher Education.* vol. 9. pp. 195–219.

Mertens, D. (2005). *Research and Evaluation in Education and Psychology*. Thousand Oaks. Sage Publications.

Miles, M. and Huberman, A. (1984). *Qualitative Data Analysis.* Beverly Hills. Sage

Millar, R., and Osborne, J. (1998). *Beyond 2000: Science education for the future.* London. King's College London.

Minichiello, V., Aroni, R. and Hays, T. (2008). *In-Depth Interviewing. 3rd Edn*. Frenchs Forest. Pearson Education Australia.

Monash Education Science Education Research Group. (2010). Online. Retrieved 18 October 2010 from http://www.education.monash.edu.au/research/groups/science/

Moustakas, C. (1994). *Phenomenological Research Methods.* Thousand Oaks. Sage Publications.

Mulholland, J., Dorman, J. and Odgers, B. (2004). Assessment of Science Teaching Efficacy of Preservice Teachers in an Australian University. *Journal of Science Teacher Education.* vol. 15. no. 4. pp. 313–331.

Murcia, K. (2005). *Science for the 21st Century: Teaching for Scientific Literacy in the Primary Classroom*. Draft paper presented at CONASTA54, University of Melbourne, 4th July 2005.

Muthukrishna, N., Camine, D., Grossen, B. and Miller, S. (1993). Children's alternative frameworks: Should they be directly-addressed in science instruction? *Journal of Research in Science Teaching*. vol. 30. no. 3. pp. 233-248

Narjaikaew, P., Emarat, N., Arayathanitkul, K., and Cowie, B. (2010). Magnetism teaching sequences based on an inductive approach for first-year Thai university science students, *International Journal of Science and Mathematics Education*. vol. 8. no. 5. pp. 891-910.

NASA Simulations. Retrieved 3 April 2009 from http://imedia.ksc.nasa.gov/index1.html

National Academies Committee on Science, Engineering, and Public Policy (COSEPUP). (2006). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Retrieved 5 October 2009 from http://www.nap.edu/catalog/11463.html#orgs

National Academy of Science. (1995). *National Science Education Standards*. Washington. National Academies Press. p. 105.

National Research Council. (NRC). (1996). *National Science Education Standards*. Washington. National Academies Press.

National Research Council. (NRC). (1999). *How people learn: Brain, mind, experience, and school*. J. D. Bransford, A. L. Brown and R. R. Cocking (Eds). Washington. National Academies Press.

National Research Council. (NRC). (2005). *How students learn: science in the classroom*. Washington. National Academies Press.

National Research Council. (NRC). (2006). *America's Lab Report: Investigations in High School Science*. Committee on High School Science Laboratories: Role and Vision. S. R. Singer, M. L. Hilton, and H. A. Schweingruber (Eds). Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC. The National Academies Press.

National Research Council. (NRC). (2010). *Learning Science Through Computer Games and Simulations*. Margaret A. Honey and Margaret Hilton (Eds.). Board on Science Education Division of Behavioural and Social Sciences and Education. Washington. National Academies Press.

National Science Board. (2006). *An Emerging and Critical Problem of the Science and Engineering Labor Force*. Arlington, VA. Retrieved 17 April 2009 from http://www.nsf.gov/statistics/nsb0407/nsb0407.pdf

National Science Teachers Association. (1992). *Scope, sequence and coordination of secondary school science: The content core, a guide for curriculum designers*. vol. 1. Washington. National Science teachers Association.

Nelson, C. (1994). Critical Thinking and Collaborative Learning. *New Directions for Teaching and Learning.* vol. 1994. no. 59. pp. 45-58.

Nelson, C. (2005). *Achievement, Equity and Retention: Three Pedagogical Changes that Can Make a Real Difference in ANY College Classroom*. Provost Lecture Series. Kansas State University. Retrieved 5 June 2009 from http://www.k-state.edu/provost/academic/lecture/2005-6/nelson.htm

Newton, L., Newton, D. and Blake, A. (2002). Understanding and Primary Science Teaching. *Investigating.* vol. 18. no. 1. pp. 11-18

Nondestructive Testing Resource Centre – Magnetism. Retrieved 9 May 2010 from http://www.ndt-ed.org/EducationResources/HighSchool/Magnetism/hs_mag_index.htm)

Norris, S. and Phillips, L. (1999). Interpreting popular reports of science: what happens when the reader's world meets the world on paper? *International Journal of Science Education.* vol. 21. no. 3. pp. 317-327.

Northfield, J. and Gunstone, R. (1983). Research on alternative frameworks: Implications for science teacher education. *Research in Science Education*. vol. 13. no. 1. pp. 185-191.

NSW Department of Education and Training. (2005). *Report of the consultation on future directions for public education and training: One size doesn't fit all*. Retrieved 17 November 2010 from https://www.det.nsw.edu.au/media/downloads/reviews/futuresproject/report/z_futuresreport.pdf

NSW Department of Education and Training. (online). Consistent Teacher Judgement. Retrieved 19 November 2011 from http://www.curriculumsupport.education.nsw.gov.au/consistent_teacher/tlcycle.htm

NSW Department of Education and Training. (2009). *What is scientific literacy?* Retrieved 16 November 2010 from www.curriculumsupport.education.nsw.gov.au/investigate/index.htm

NSW Department of Education and Training. (2010). *Curriculum Planning Framework with Programming Support: Units of Work.* Retrieved 30 June 2010 from http://www.curriculumsupport.education.nsw.gov.au/timetoteach/cogs/unitsintro.htm

NSW Teachers. (2010). *Graduate Teacher Standards*. Retrieved 22 November 2010 from http://www.nswteachers.nsw.edu.au/Subject-content-requirements-abridged.html

Nussbaum, J. and Novick, S. (1983). Alternative frameworks, conceptual conflict and accommodation: Toward a principled teaching strategy. *Instructional Science*. vol. 11. no. 3. pp. 183-200

Organisation for Economic Cooperation and Development. (OECD). (2006). *Evolution of Student Interest in Science and Technology Studies: Policy Report*. Paris. OECD. Global Science Forum.

Osborne, J. and Dillon, J. (2008). *Science Education in Europe: Critical Reflections*. A report to the Nuffield Foundation. London

Osborne, J., Black, P., Smith, M. and Meadows, J. (1991). *Primary SPACE project research report: Electricity*. Liverpool, UK. Liverpool University Press.

Osborne, R. (1981). Children's ideas about electric current. *New Zealand Science Teacher*. vol. 29. pp. 12–19.

Palmer, D. (1995). The 'POE' in the primary school: an evaluation. *Research in Science Education*. vol. 25. no. 3. pp. 323-332.

Palmer, D. (2008). Practices and Innovations in Australian Science Teacher Education Programs. *Research in Science Education.* vol. 38. pp. 167-188.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York. Basic Books.

Patterson, M. (1946). Shortage of Scientists. *The Science News-Letter*. vol. 50. no. 14. pp. 218-220.

Patton, M. (2002). Qualitative research and evaluation methods (3rd Ed.). Thousand Oaks. Sage.

Peers, C. (2006). *Making a difference: Primary Connections Stage 3 Project Brief.* Canberra. Australian Academy of Science.

Peers, C. (2007). *Minds-on, Hands-on: Creating competent and confident teachers of science and literacy*. Retrieved 11 February 2010 from http://www.science.org.au/primaryconnections/about/images/news-feature-science.pdf

Pellegrino, J. (2003). *The Challenge of Knowing What Students Know*. Retrieved 8 July 2009 from http://bearcenter.berkeley.edu/oldmirp/docs/CommentaryRevisedPellegrino.pdf

Pellegrino, J., Chudowsky, N. and Glaser, R. (Eds.). (2001). *Knowing What Students Know: The Science and Design of Educational Assessment*. Board on Testing and Assessment, Center for Education, National Research Council. Washington. National Academies Press.

Perry, W. (1970). *Forms of Intellectual and Ethical Development in the College Years: A Scheme.* New York. Holt, Rinehart and Winston.

Peterson, P., Fennema, E., Carpenter, T. and Loef, M. (1989). Teachers' pedagogical content beliefs in mathematics. *Cognition and Instruction.* vol. 6. no. 1. pp. 40-46.

Phillips, D. (1995). The good, the bad and the ugly: The many faces of constructivism. *Educational Researcher.* vol. 24. vo. 7. pp. 5-12.

Piaget, J. (1954). *The construction of reality in the child.* New York. Basic Books.

Plourde, L. (2002). Elementary science education: the influence of student teaching - where it all begins. *Education*. Winter. Retrieved 10 April 2010 from http://findarticles.com/p/articles/mi_qa3673/is_2_123/ai_n28970303/?tag=content;col1

Pope, M. and Gilbert, J. (1983). Personal experience and the construction of knowledge in science. *Science Education.* vol. 67. no. 2.

Posner, G., Strike, K., Hewson, P. and Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*. vol. 66. no. 2. pp. 211-227

Prosser, M. (1993). Phenomenography and the Principles and Practices of Learning. *Higher Education Research & Development.* vol. 12. no. 1. pp. 21-31

Prosser, M. (2000). Using phenomenographic research methodology in the context of research in teaching and learning. In John A. Bowden and Eleanor Walsh (Eds.). *Phenomenography.* Melbourne. RMIT University Press. pp. 34-46.

Prosser, M., and Trigwell, K. (1999). *Understanding Learning and Teaching : the experience in higher education.* The Society for Research into Higher Education and Open University Press. Maidenhead. McGraw-Hill

Psillos, D. (1998). Teaching Introductory Electricity. In Andrée Tiberghien, A., Jossem, L. and Barojas, J. (Eds.). *Connecting Research in Physics Education with Teacher Education*, An I.C.P.E. Book

Raduta, C. (2005). *General students' misconceptions related to Electricity and Magnetism*. Retrieved 29 August 2009 from http://arxiv.org/pdf/physics/0503132v1

Ravanis, K., Pantidos, P. and Vitoratos, E. (2009). *Magnetic Field Mental Representation of 14-15 years old students*. Retrieved 16 October 2009 from http://dppd.ubbcluj.ro/adn/article_2_2_1.pdf

Rebello, N. and Fletcher, P. (2006). A Framework for Integrated Professional Development. Paper presented at *Proceedings of the NARST 2006 Annual Meeting*. April, 2006: San Francisco.

Redish, E., Wilson, J. and McDaniel, C. (1992). *The CUPLE Project: A Hyper- and Multi-Media Approach to Restructuring Physics Education*. Retrieved 28 March 2009 from http://www.eric.ed.gov:80/PDFS/ED438180.pdf

Rennie, L. (2006). *The community's contribution to science learning: Making it count*. Report presented at the 2006 ACER Conference. Retrieved 19 November 2009 from http://research.acer.edu.au/research_conference_2006/8

Rennie, L., Goodrum, D. and Hackling, M. (2001). Science teaching and learning in Australian schools: Results of a national study. *Research in Science Education.* vol. 31. pp. 455-498.

Richardson, J. (2004). Concept Inventories: Tools For Uncovering STEM Students' Misconceptions. *Assessment and Education Research.* Tuscaloosa. University of Alabama.

Riess, F. (2000). Problems with German Science Education. *Science & Education*. vol. 9. pp. 327-331

Robbins, D. (2001). *Vygotsky's Psychology-Philosophy: A Metaphor for Language Theory and Learning.* New York. Kluwer Academic/Plenum Publishers.

Robinson, S., Goldberg, F. and Otero, V. (2005). *Physics for Elementary Teachers: A New Curriculum*. APS Forum on Education. Summer 2005 Newsletter pp. 27-32.

Roth, K., Druker, S., Garnier, H., Lemmens, M., Chen, C., Kawanaka, T., Rasmussen, D., Trubacova, S., Okamoto, Y., Gonzales, P., Stigler, J., and Gallimore, R. (2006). *Highlights from the TIMSS 1999 Video Study of eighth-grade science teaching* (NCES 2006-17). U.S. Department of Education, National Center for Education Statistics. Washington. U.S. Government Printing Office.

Rutherford, J. (2005). The 2005 Paul F-Brandwein Lecture: Is Our Past Our Future? Thoughts on the Next 50 Years of Science Education Reform in the Light of Judgments on the Past 50 Years. *Journal of Science Education and Technology.* vol. 14. no. 4

Salganik, M. and Heckathorn, D. (2004). Sampling and Estimation in Hidden Populations Using Respondent-Driven Sampling. *Sociological Methodology.* vol. 34. pp. 193–239.

Sampayo, M. (2006). *Engineering Problem Solving: The Case of the Laplace Transform as a Difficulty in Learning in Electric Circuits and as a Tool to Solve Real World Problems*. Unpublished PhD Thesis. Retrieved 19 November 2010 from http://www.didaktik.itn.liu.se/thesis/margarita_thesis2.pdf

Schwartz, M., Hazari, Z. and Sadler, P. (2008). Divergent Views: Teacher and Professor Perceptions About Pre-College Factors That Influence College Science Success. *Science Educator*. vol. 17. no. 1. pp. 18-37.

Science, Technology, Engineering and Mathematics (STEM) Software. Retrieved 16 August 2009 from http://scatter.colorado.edu/STEM-TPSoft/

Scott, P., Asoko H. and Driver, R. (1994). Teaching for conceptual change: A review of strategies in R. Duit, F. Goldberg and H. Niedderer (Eds.) *Research in Physics Learning: Theoretical Issues and Empirical Studies.* Keil. Proceedings of an International Workshop. pp. 310-329.

SCEVT (Standing Committee on Education and Vocational Training). (2007). *Top of the Class: Report on the Inquiry into Teacher Education*. Canberra. Australian House of Representatives. Retrieved 23 December 2010 from www.aph.gov.au/house/committee/evt/teachereduc/report.htm

Sefton, I. (2002). *Understanding Electricity and Circuits: What the Text Books Don't Tell You*. Science Teachers Workshop 2002. Retrieved 16 June 2009 from http://sydney.edu.au/science/uniserve_science/school/curric/stage6/phys/stw2002/sefton.pdf

Shaffer, P. and McDermott, L. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. *Am. J. Phys*. vol. 60. p. 1003

Sharma, M. (2010). Why Science Lessons are Boring. *Cosmos.* 17 November 2010. Retrieved 2 February 2011 from http://www.cosmosmagazine.com/features/online/3867/school-science-too-boring?page=0%2C1

Sherman, A. and MacDonald, L. (2007). Pre-service Teachers Experiences with a Science Education Module. *Journal of Science Teacher Education.* vol. 18. pp. 525–541.

Shipstone, D. (1984). A study of children understanding simple DC circuits. *European Journal of Science Education.* vol. 6. no. 2. pp. 185–198.

Simanek D. (2008). *Didaktikogenic Physics Misconceptions Student misconceptions induced by teachers and textbooks*. Retrieved 19 May 2009 from http://www.lhup.edu/~dsimanek/scenario/miscon.htm

Sjoberg, S. (2007). Constructivism and Learning. In Baker, E., McGaw, B. & Peterson, P. (Eds.). *International Encyclopaedia of Education. 3rd Edition.* Oxford. Elsevier.

Skamp, K. (Ed.). (2008). *Teaching Primary Science Constructively. 3rd Edition*. Sydney. Nelson Australia.

Slavin, R. (1994). *Using Student Team Learning. 4th Edition*. Baltimore. Johns Hopkins University, Center for Social Organization of Schools.

Smith, D. and Neale, D. (1991). The construction of subject matter knowledge in primary science teaching. *Advances in Research on Teaching.* vol. 2. pp. 187–243.

Smith, H. (1975). *Strategies of Social Research: The Methodological Imagination.* London. Prentice Hall.

Smith, J., diSessa, A. and Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of Learning and Sciences.* vol. 3. no. 2. pp. 115-163.

So, W. (2002). Constructivist Teaching in Primary Science. *Asia-Pacific Forum on Science Learning and Teaching*. vol. 3. no. 1.

Solomon, J. (1994). The Rise and Fall of Constructivism. *Studies in Science Education.* vol. 23. pp. 1-19.

Solomon, J., Black, P., Oldham, V. and Stuart, H. (1985). The pupils' view of electricity. *European Journal of Science Education*. vol. 7. no. 3. pp. 281–294.

Solomonidou, C. and Kakana, D.-M. (2000). Preschool children's conceptions about the electric current and the functioning of electric appliances. *European arly Childhood Education Research Journal*. vol. 8. no. 1. pp. 95-111.

Sorin, R. and Klein, M. (2002). *Walking the walk and talking the talk – adequate teacher preparation in these uncertain times*. Retrieved 18 May 2009 from http://www.aare.edu.au/02pap/sor02045.htm

Steffe, L. and Gale, J. (Eds.). (1995). Constructivism in education. Hillsdale. Lawrence Erlbaum Associates.

Steinert, Y. and Snell, L. (1999). Interactive lecturing: strategies for increasing participation in large group presentations. *Medical Teacher*. vol. 21. no. 1. pp 37-42.

Stocklmayer, S. and Treagust, D. (1996). Images of electricity, how do novice and experts model electric current. *International Journal of Science Education*. vol. 18. no. 2. pp. 163–178.

Strike, K., and Posner, G. (1982). Conceptual Change and Science Teaching. *International Journal of Science Education*. vol. 4. no. 3. pp. 231-240. Retrieved 7 February 2010 from http://dx.doi.org/10.1080/0140528820040302

Sutching, W. (1992). Constructivism Deconstructed. *Science & Education.* vol. 1. no. 3. pp. 223-254.

Swartz, C. (2006). Cliff's Nodes. *Editorials from The Physics Teacher*. Maryland. The John Hopkins University Press.

Switched on Kids – How to use Electricity Safely. Retrieved 22 May from http://www.switchedonkids.org.uk/

Sydney University Physics Education Research (SUPER) Project. Retrieved 16 August 2009 from http://www.physics.usyd.edu.au/super/

Taber, K. (2006). Beyond Constructivism: the Progressive Research Programme into Learning Science. *Studies in Science Education.* vol. 42. pp 125-184.

Taber, K., de Trafford, T. and Quali, T. (2006). Conceptual resources for constructing the concepts of electricity: the role of models, analogies and imagination. *Physics Education*. vol. 41. no. 2. pp. 1550160.

Tairab, H. (2010). Assessing science teachers' content knowledge and confidence in teaching science: how confident are UAE prospective elementary science teachers? *International Journal of Applied Educational Studies.* vol. 7. no. 1. pp. 59-72.

Tanel, Z. and Erol, M. (2008). Students' Difficulties in Understanding the Concepts of Magnetic Field Strength, Magnetic Flux Density and Magnetization. *Latin American Journal of Physics Education*. vol. 2. pp. 184-191.

Technology Enabled Active Learning (TEAL). Retrieved 16 August 2009 from http://web.mit.edu/8.02t/www/802TEAL3D/visualizations/guidedtour/GuidedTour.htm

Tharp, R. and Gallimore, R. (1988). *Rousing Minds to Life: Teaching, Learning, and Schooling in Social Context.* Cambridge. Cambridge University Press

Thomasnet – More about Magnets. Retrieved 22 March 2010 from http://www.thomasnet.com/about/magnets-49490402.html

Thomson, S. and De Bortoli, L. (2007). *Exploring Scientific Literacy: How Australia measures up*. The PISA 2006 survey of students' scientific, reading and mathematical literacy skills. Melbourne. ACER. Retrieved 3 July 2008 from http://www.acer.edu.au/documents/PISA2006_Report.pdf

Thomson, S., Wernert, N., Underwood, C. and Nicholas, M. (2008). *TIMSS 07: Taking a closer look at mathematics and science in Australia*. Melbourne. ACER.

Tiberghien, A., Jossem, E. and Barojas, J. (1998). *Connecting Research in Physics Education with Teacher Education*. An I.C.P.E. Book. International Commission on Physics Education. UNESCO.

Tobin, K. (1993). Referents for Making Sense of Science Teaching. *International Journal of Science Education.* vol. 15. no. 3.

Tobin, K., Briscoe, C. and Holman, J. (1990). Overcoming constraints to effective elementary science teaching. *Science Education.* vol.74. no. 4

Tosun, T. (2010). The Beliefs of Preservice Elementary Teachers Toward Science and Science Teaching. *School Science and Mathematics*. vol. 100. no. 7. pp374-379.

Treagust, D. (1993). The Evolution of an Approach for Using Analogies in Teaching and Learning Science. *Research in Science Education*. vol. 23. no. 1. pp. 293-301.

Treagust, D and Duit, R. (2009). Multiple perspectives of Conceptual Change in Science and the Challenges Ahead. *Journal of Science and Mathematics Education in Southeast Asia.* vol. 32. no. 2. pp. 89-104

Trigwell, K., Prosser, M., Ramsden, P., and Martin, E. (1998). Improving student learning through a focus on the teaching context. In Rust, C. (Ed.). *Improving Student Learning.* Oxford. Oxford Centre for Staff and Learning Development. pp. 97–103.

Trumper, R. (2006). Factors Affecting Junior High School Students' Interest in Physics. *Journal of Science Education and Technology*. vol. 15. no. 1. pp. 47-58.

Tsai, C. (2003). Using a conflict map as an instructional tool to change student alternative conceptions in simple series electric – circuits. *International Journal of Science Education*. vol. 25. pp. 307 – 327.

Tytler, R. (2007). *Re-imagining Science Education – Engaging students in science for Australia's future*. Canberra. ACER.

Tytler, R., and Symington, D. (2006). Science in school and society. *Teaching Science: Journal of the Australian Science Teachers Association*. vol. 52. no. 3. pp.10–15.

UK House of Commons Select Committee on Science and Technology. Roberts Review (2002). *Third report: Science education from 14 to 19*. Retrieved 16 October 2009 from http://www.publications.parliament.uk/pa/cm200102/cmselect/cmsctech/508/50802.htm

van der Veer, R. and Valsiner, J. (1991). *Understanding Vygotsky: A Quest for Synthesis*. Oxford. Blackwell.

van Heuvelen, A. (1999). Research about physics learning, linguistics, our minds, and the workplace. *Announcer.* vol. 29. no. 2.

van Hook, S. and Huziak-Clark, T. (2007). Tip-to-tail: developing a conceptual model of magnetism with kindergartners using inquiry-based instruction. *Journal of Elementary Science Education.* vol. 19. no.2. pp. 45-60.

van Manen, M. (1984). Practising phenomenological writing. *Phenomenology and Pedagogy.* vol. 2. no. 1. pp. 36-69.

van Manen, M. (1990). Researching Lived Experience: Human Science for an Action Sensitive Pedagogy. New York. State University of New York Press.

van Rossum, E. and Schenk, S. (1984). The relationship between learning conception, study strategy and learning outcome. *British Journal of Educational Psychology.* vol. 54. pp. 73-83.

Victorian Parliament Education and Training Committee. (2006). *Inquiry into the promotion of mathematics and science education*. Melbourne. Victorian Government.

von Glasersfeld, E. (1989). Cognition, construction of knowledge and teaching. *Synthese.* vol. 80. no. 1. pp. 121-140.

Vygotsky, L. (1962-1986). *Thought and Language*. Massachusetts. The M.I.T. Press.

Vygotsky, L. (1978). *Mind and society: The development of higher mental processes*. Cambridge. Harvard University Press.

Walker-Bartnick, L., Berger, J. and Kappelman, M. (1984). A model for peer tutoring in the medical school setting. *Journal of Medical Education*. vol. 59. pp. 309–315.

Walsh, E., Dall'Alba, G., Bowen, J., Martin, E., Marton, F., Masters, G., Ramsden, P. and Stephanou, A. (1993). Physics Students' Understanding of Relative Speed: A Phenomenographic Study, *Journal of Research in Science Teaching.* vol. 30. no. 9. pp. 133-148.

Watters, J. and Ginns, I. (2000). Developing motivation to teach elementary science: Effect of collaborative and authentic learning practices in pre-service education. *Journal of Science Teacher Education.* vol. 11. pp. 301-321.

Watters, J. and Ginns, I. (2000). Developing motivation to teach elementary science: Effect of collaborative and authentic learning practices in pre-service education. *Journal of Science Teacher Education.* vol. 11. pp. 301-321.

Weiss, I. (1994). *A profile of science and mathematics education in the United States: 1993*. A report for the National Science Foundation, Chapel Hill, NC. Horizon Research Inc.

Wilson, J. (1994). The CUPLE Physics Studio. *Physics Teacher*. vol. 32. no. 9. pp. 518-523.

Winters, V., and Hammer, D. (2009). *Fourth Graders' Framing of an Electric Circuits Task*. Paper presented at Physics Education Research Conference 2009. Ann Arbor, Michigan. Retrieved 12 August 2010, from http://www.compadre.org/Repository/document/ServeFile.cfm?ID=9509&DocID=1384

Woolnough, B. (1989). Towards a holistic view of processes in science education. In Jerry Wellington (Ed.) *Skills and Processes in Science Education: a Critical Analysis*. pp. 115-134. London. Routledge.

Woolnough, B. (1998). Learning Science is a Messy Process. *Science Teacher Education*. vol. 23. pp16-33.

Yager, R. (2007) The Centrality of Inquiry to Reforms in Science Education. *The Science Education Review*. vol. 6. no. 3. pp. 104-113.

Young, B. and Lee, S. (2005). The Effects of a Kit-Based Science Curriculum and Intensive Science Professional Development on Elementary Student Science Achievement. *Journal of Science Education and Technology*. vol. 14. no. 5.

APPENDIX A

HUMAN ETHICS APPROVAL DOCUMENTATION AND FINAL RESEARCH INSTRUMENT

This Appendix contains the following University of New England, Human Ethics Documentation (Approval No. HE09/003, Valid to 30/06/2010):

1. Student – Pre- and Post-Intervention Survey
2. Assessment Rubric
3. Guided Activity Booklet – Phase II Research Instrument EDSE213
4. Guided Activity Booklet – Phase III Research Instrument EDSE213
5. Guided Activity Booklet – Phase IV Research Instrument EDSE412

Please note:

I. The Pre- and Post-intervention surveys were applied during each of Phases II and III.

II. Some pages of the Final Research Instrument Guided Activity Booklet have been omitted as they were blank pages seeking responses to open-ended questions posed earlier in the booklet as part of the interactive lecture.

III. Full copies of all data collection documentation are available from the author bruce.mcmullen@une.edu.au

APPENDIX A.1

Electricity and Magnetism

PRE- AND POST-INTERVENTION SURVEY

Pseudonym: ______________________________________

1. List in each of the columns things that use electricity, and those that use magnetism.

Electricity	Magnetism

(space omitted here)

---

2. Please describe what you understand to be the meaning of the term "electricity".

(space omitted here)

---

3. Please describe what you understand to be the meaning of the term "magnetism".

(space omitted here)

---

4. Are there any relationships between electricity and magnetism that you know of?

(space omitted here)

---

5. What is the difference between AC and DC?

(space omitted here)

---

6. List all the ways that you know how electricity may be made?

(space omitted here)

---

7. Can you describe one way that electricity is made?

(space omitted here)

---

8. From your own personal perspective, please rate your confidence in delivering the topic of Electricity and Magnetism to Stage 2.

(circle the number closest)

1	2	3	4	5	6	7	8	9	10
Least									Most

a. Please identify what areas of Electricity and Magnetism that you believe you are **confident** to teach.

---

b. Please identify the areas of Electricity and Magnetism you believe you are **least confident** to teach.

(space omitted here)

APPENDIX A.2

Electricity and Magnetism

PRE- AND POST-INTERVENTION SURVEY ASSESSMENT RUBRIC

Category	Below Expected Level	At Expected Level	Above Expected Level
Definitions			
Electricity Uses	Identifies less than 10 uses of electricity.	Identifies between 10 and 15 uses of electricity.	Identifies more than 15 uses of electricity.
Electricity	Referred to as a source of power without reference to the scientific explanation, and without any appropriate terminology.	Mention is made to the movement of electrons or charge, without reference to conduction, and without appropriate terminology.	Defines electricity as the movement of electric charge through space, or electrons through a conductor incorporating such terms as current and voltage.
Uses of Magnets	Identifies less than 5 uses of magnets.	Identifies between 5 and 10 uses of magnets.	Identifies more than 10 uses of magnets.
Magnetism	Refers to the property of attraction only. Describes poles as being positive or negative. Defines magnets as being metals that can attract other metals.	Recognises polarity as North and South. Describes the conditions necessary for magnets to attract other objects and magnets, and to repel other magnets. No reference to magnetic field.	Refers to, and describes the conditions necessary for both the attractive and repulsive properties of magnets to be exhibited in proximity. Describes North and South poles. Makes reference to magnets as having a field. Identifies metals able to exhibit magnetic properties.
Relationship between Electricity and Magnetism	None stated.	Refers to the term ‘electromagnet’ without describing how electromagnets work.	Makes reference to electromagnetism and/or electromagnetic waves. Describes electromagnets as electricity flowing through a coil of wire wrapped around a metal.

Difference between AC and DC	None stated.	Able to name them as Direct and Alternating Current.	Describes them in terms of the flow of charge/electrons through a conductor.
Sources of/generation of Electricity	Less than 2 identified.	Lists between 3 and 5 sources of electricity without reference to ways to generate electricity.	Lists at least 3 sources of electricity AND at 2 ways to generate electricity.
Diagrams			
Format of Diagram	Drawing representing a 3-dimensional image of the circuit.	Diagram contains some elements of circuit diagram and appropriate symbols.	Diagram resembles a circuit diagram.
Labels	No labels provided on the diagrams.	Some of the elements of the diagram labelled correctly.	All of the components of the diagram provided are correctly labelled.

Note: Expected Level is defined as a basic understanding that meets the outcome statements described in the NSW *Science and Technology K-6*: *Syllabus and Support Document* (BoS NSW 1993), and further elaborated upon by the Connected Outcomes Groups marking rubric for the Curriculum Support arm of the NSW Department of Education and Training (2010).

Each of the student responses to the pre- and post-intervention surveys were independently assessed, using the above rubric, by at least two members of the research team, to ensure iterator reliability.

Electricity and Magnetism

Teaching Strategies

Team name: ____

APPENDIX A.3

EDSE213_2009 – GUIDED ACTIVITY WORK-BOOKLET

☐ Ticking this box signifies that we have read the Participant Information sheet associated with this research project and we give our consent for this work to be collected and analysed as part of the *Electricity and Magnetism Pedagogies for Pre-service Teachers project.*

This project has been approved by the Human Research Ethics Committee of the University of New England (Approval No. HE09/003 valid to 30/06/2010). Should you have any complaints concerning the manner in which this research is conducted, please contact the Research Ethics Officer at the following address: Research Services. University of New England. ARMIDALE. NSW 2351. Telephone: (02) 7673349; Facsimile: (02) 67733543; Email: Ethics@pobox.une.edu.au

WORKSHOP 1.

1. How would you find out about what your students know about a particular concept? Make a list in the left hand column below.

Discuss your ways with your colleagues and write your amended list in the right hand column.

My list about finding out	Collaborated list about finding out
(space omitted here)	

Please turn to page 16 and spend the next 15 minutes completing the pre-intervention survey.

2. *Predict-Observe-Explain* is a well-known teaching strategy where students are encouraged to use and develop their observational, recording and thinking skills.

The example presented is about dropping a button magnet down a piece of aluminium tube.
In the space below, predict what you think will happen.

(space omitted here)

Watch carefully, and record what you saw happen.

(space omitted here)

Try to explain your observation.

(space omitted here)

Share your explanation with your group members – has your possible explanation changed? If so, how and why.

(space omitted here)

3. **Another P-O-E.**

In the space below, please draw the **circuit** shown to you.

(space omitted here)

Predict what will happen when the battery is connected in this circuit**.**

(space omitted here)

Record your observation.

(space omitted here)

Try to **explain** everything you observed.

(space omitted here)

Share your explanation. Did your explanation change, and if so, how?

(space omitted here)

What makes the light glow? With reference to your diagram above, describe, using your own words, labels, arrows etc., all of the processes happening in this circuit.

(space omitted here)

In **collaboration** with your other group members, discuss your thoughts about what ideas your students may have about this activity. What ideas might your students use to explain this activity.

Stage 1

(space omitted here)

Stage 2

(space omitted here)

Stage 3

(space omitted here)

In collaboration with your other group members, discuss and list the **difficulties** might you face trying to teach this component of the syllabus?
(space omitted here)

List other activities you would use with your class to explore the concepts associated with batteries, lights and wires.
(space omitted here)

4. **Time to EXPLORE – Magic with Magnets**

You have been given 8 magnets – 2 bar magnets, 2 horseshoe magnets, 2 button magnets and 2 fridge magnets.

Play with them to see how they interact.

From the things around you, prepare a **list** of things that are magnetic and those that are not.
(space omitted here)

Describe in your own words the properties of each of the different kinds of magnets.

Bar:

Horseshoe:

Button

Fridge:

5. **POEs as a DEMONSTRATION**

Predict - What will happen to the needle of the meter (that is used to measure the flow of electricity) when a bar magnet is moved into the big coil of wire
(space omitted here)

Observe – record – share your observations with others in your group.
Anything you want to try? (student questions)
(space omitted here)

COLLABORATION and DISCUSSION - What have you learned from your observations?
A magnet moving inside a coil makes electricity.

What about the OPPOSITE? What do you think moving electricity inside a coil of wire makes ????

We will **explore** shall we?
DEMONSTRATION: coil of wire connected to a battery brought near to a compass.

6. Each of your groups has been given a **shaky torch**. In the space below, draw and label the torch and try to **explain what each of the components** you have labelled actually do.

(space omitted here)

Compare your explanations with other members of your group and in a separate list, record your agreed explanations of the workings of your labelled components.

(space omitted here)

---

7. From your own personal perspective, please rate your **confidence** in delivering this to Stage 2.

1	2	3	4	5	6	7	8	9	10
Least								Most	

Please identify what areas of electricity you believe you are confident to teach.

(space omitted here)

Please identify what areas of electricity you believe you are not confident to teach.

(space omitted here)

Outline what life experiences you have had, at school or university, dealing with electricity and magnetism.

(space omitted here)

LECTURE

NOTE: Feedback Notes for Discussion are not included here: a full copy of these notes is provided in Appendix D.5.

1. **Review – the Shaky (Faraday) Torch revisited**

This was an example of an ENGAGE activity.
Now, it can be an explore activity too –
Spend the next 10 minutes or so, playing with the torch and, reflecting on what we shared and negotiated in the first workshop, try to figure out, in collaboration with your group,
How does it work? – record – in the space below your negotiated explanation.
(space omitted here)

Where does the energy come from? – in the space below your negotiated explanation.
(space omitted here)

Discussion – Do you think that Collaboration with your group has amended your understanding?

2. **Make the Globe Light Up.**

You have been given one 'C' cell, one piece of wire, and one light bulb. Devise a way of making the light bulb light.

Without looking at your neighbour, please draw a **diagram** of what you plan to try first.
(space omitted here)

Try your way – did it work? If not, try another way, and keep trying until it does – consult with others in your group.

Without amending your previous diagram, now that you have solved the problem and got it to work, please redraw and label your working design in the space below.
(space omitted here)

Report any difficulties you had in getting it to work.
(space omitted here)

If you gave this activity to your students in Stage 2, what would you want them to discover/learn?
(space omitted here)

---

3. **Making an electromagnet.**

You remember seeing a great activity just using some wire, a nail and a battery. With these basic components the demonstrator was able to pick up a paperclip.

You are thinking about using this activity with your class and sit down with your colleagues to discuss the best way to do it.

Working collaboratively with the other three members of your group, make a device to attract and pick-up a paperclip using a metre of wire, a nail, and a 'C' cell.

In this workbook, in your own way (words, diagrams, labels etc.), please describe what is happening in your device to make it attract and pick-up a paperclip.
(space omitted here)

---

6. **Does it work as well without the nail in the centre of the coil? Try a different centre? Report on your findings.**

(space omitted here)

---

7. In the table below, list as many things as you can that involve the **use of magnets** in the first column, identify the type of magnet in the second column, and describe the purpose of the magnet in the final column.

Item using a magnet	Type/shape etc. of magnet	Purpose of the magnet
(space omitted here)		

4. **How would you explain each of these things to an alien (assuming a common language)?**

Magnet:
(space omitted here)

Electricity:
(space omitted here)

Charge:
(space omitted here)

Magnetic field:
(space omitted here)

Electric motor:
(space omitted here)

WORKSHOP 2.

1. **Discussion regarding effectiveness of collaborative learning**:
Does it work? Please explain your answer after discussing it with your colleagues.
(space omitted here)

---

2. **A better electromagnet**.
Reflecting on your activity where you designed and made an electromagnet to pick-up one paperclip, consider the following challenges.

Think carefully about how you may amend your design to pick up more paperclips.

Predict how you will change your design, and the change in performance you expect.

Draw and label your new model.
(space omitted here)

Consult with your colleagues and come up with a collaborative design.
Draw your new negotiated model.
(space omitted here)

Construct your new and improved model.

Observe and record how many paper clips you can now pick up and hold for 5 seconds.

Explain why your improved model works better.
(space omitted here)

---

3. **P-O-Es – a review**
Let us reflect upon and discuss the P-O-Es you experienced during the lecture in terms of the value of the exercise as a learning experience.

Your turn – in the space below, design your own POE for an electric or magnetic concept of your choice for a Year 4 class.
(space omitted here)

Why did you choose this concept ?
(space omitted here)

---

4. **More Definitions**
– what do you know about (guide me to design experiences for you to improve your understanding – a form of formative assessment)
In the space below,

In terms of electricity, what is your understanding of electrical **power**?
(space omitted here)

List from your experience where you have seen the term **volts**? Share with your neighbour.
(space omitted here)

List from your experience where you have seen the term **amps**? Share with your neighbour.
(space omitted here)

List from your experience where you have seen the term **watts**? Share with your neighbour.
(space omitted here)

---

5. **Making An Electric Motor.**

We are going to allow electricity to flow intermittently through a coil of wire and allow it to interact with a permanent magnet.

Step 1: make your coil – using 1m of enamelled copper wire

Step 2: shape your paperclips so they will be able to cradle your coil.

Step 3: tape the paperclips to a size 'C' dry cell so that the coil spins freely (balancing required). Place a small piece of blue tac or plasticine on the bottom of the magnet so it is secure.

Step 4: Place a button magnet on the top of the cell and below the coil. If necessary, tap the coil to start the motion.

Step 5: If your motor does not work, look around and seek the advice of your colleagues.

Equipment provided:

1m enamelled copper wire	2 paper clips
1 size 'C' dry cell	insulation tape
sand paper	blue tac

Draw and LABEL your final motor – in your own words, try to explain how it works.

(space omitted here)

What was the most interesting part of building the motor for you?

(space omitted here)

Can you think of anything you could do with your motor to make it a better activity with your students?

(space omitted here)

---

6. A Review.

- From the list of activities you experienced during the Electricity and Magnetism sequence, please identify ONE activity you enjoyed during the Electricity and Magnetism sequence you experienced and explain why you chose it – what did you learn from the activity?

(space omitted here)

- Now that you have worked a little with compasses, can you describe how a compass works?

(space omitted here)

- Can you think of any other things that compasses could be used for apart from pointing a particular direction?

(space omitted here)

- Now that you have built an electric motor, please describe the purpose of:
    - The coil:

(space omitted here)

- The magnet:

(space omitted here)

- An interesting result from the lecture notes and worksheets I have analysed suggests that there is some confusion about the poles of a magnet. Some of you described the ends of a magnet as positive and negative, whilst others named the poles as North and South. Can you describe a possible reason for of this confusion, and how would you as a teacher may address it?

(space omitted here)

APPENDIX A.4

Electricity and Magnetism

Teaching Strategies

Team name: ____

EDSE213_2010 – GUIDED ACTIVITY WORK-BOOKLET

☐ Ticking this box signifies that we have read the Participant Information sheet associated with this research project and we give our consent for this work to be collected and analysed as part of the *Electricity and Magnetism Pedagogies for Pre-service Teachers project.*

This project has been approved by the Human Research Ethics Committee of the University of New England (Approval No. HE09/003 valid to 30/06/2010). Should you have any complaints concerning the manner in which this research is conducted, please contact the Research Ethics Officer at the following address: Research Services. University of New England. ARMIDALE. NSW 2351. Telephone: (02) 7673349; Facsimile: (02) 67733543; Email: Ethics@pobox.une.edu.au

You will use this workbook for the two lectures, today and next week. The workbook will be collected from you at the end of the lecture, copied, and returned to you at the commencement of the next lecture.

LECTURE 1.

1. How would you find out about what your students know about a particular concept? Make a list in the left hand column below.

Discuss your ways with your colleagues and write your amended list in the right hand column.

My list about finding out	Collaborated list about finding out
(space omitted here)	

Please turn to page 18 and spend the next 15 minutes completing the pre-intervention survey.

2. *Predict-Observe-Explain* is a well-known teaching strategy where students are encouraged to use and develop their observational, recording and thinking skills.

The example presented is about dropping a button magnet down a piece of aluminium tube.
In the space below, predict what you think will happen.
(space omitted here)

Watch carefully, and record what you saw happen.
(space omitted here)

Try to explain your observation.
(space omitted here)

Share your explanation with your group members – has your possible explanation changed? If so, how and why.
(space omitted here)

---

3. **Another P-O-E.** In the space below, please draw the **circuit** shown to you.

(space omitted here)

Predict what will happen when the battery is connected in this circuit**.**
(space omitted here)

Record your observation.
(space omitted here)

Try to **explain** everything you observed.
(space omitted here)

Share your explanation. Did your explanation change, and if so, how?
(space omitted here)

What makes the light glow? With reference to your diagram above, describe, using your own words, labels, arrows etc., all of the processes happening in this circuit.
(space omitted here)

In **collaboration** with your other group members, discuss your thoughts about what ideas your students may have about this activity. What ideas might your students use to explain this activity.

Stage 1
(space omitted here)

Stage 2
(space omitted here)

Stage 3
(space omitted here)

In collaboration with your other group members, discuss and list the **difficulties** might you face trying to teach this component of the syllabus?
(space omitted here)

List other activities you would use with your class to **explore** the concepts associated with batteries, lights and wires.
(space omitted here)

LECTURE 2.

1. **Time to EXPLORE - What things are magnetic?**

You have been given 8 magnets – 2 bar magnets, 2 horseshoe magnets, 2 button magnets and 2 fridge magnets.

Play with them to see how they interact.

From the things around you, prepare a **list** of things that are magnetic and those that are not.
(space omitted here)

Describe in your own words the properties of each of the different kinds of **magnets**.

Bar:

Horseshoe:

Button

Fridge:

---

2. Each of your groups has been given a **shaky torch**. In the space below, draw and label the torch and try to **explain what each of the components** you have labelled actually do.

(space omitted here)

Compare your explanations with other members of your group and in a separate list, record your agreed explanations of the workings of your labelled components.
(space omitted here)

---

3. **POEs as a DEMONSTRATION**

Predict – The equipment set up is a coil of **insulated** copper wire in a circuit with a large demonstration meter that measures the flow of electricity)
Predict what will happen when a bar magnet is moved around near to, but outside the coil.
(space omitted here)

Observe and record your observations.
(space omitted here)

Predict what will happen when a bar magnet is moved into the coil.
(space omitted here)

Observe – record your observations.
(space omitted here)

Predict what will happen when a bar magnet is moved back out of the coil.
(space omitted here)

Observe – record your observations.
(space omitted here)

Predict what will happen if the magnet is stationary.
(space omitted here)

Anything you want to try? (student questions)

4. **COLLABORATION and DISCUSSION** - What have you learned from your observations?

A magnet moving inside a coil makes electricity.

What about the OPPOSITE? What do you think moving electricity inside a coil of wire makes ???? We will **explore** shall we?

5. **DEMONSTRATION**: coil of wire connected to a battery brought near to a compass.

From your own personal perspective, please rate your confidence in delivering this to Stage 2.

1	2	3	4	5	6	7	8	9	10
Least									Most

Please identify what areas of electricity you believe you are confident to teach.
(space omitted here)

Please identify what areas of electricity you believe you are not confident to teach.
(space omitted here)

Outline what life experiences you have had, at school or university, dealing with electricity and magnetism.

(space omitted here)

Electricity and Magnetism

Workshops EDSE213: **Thursday April 1st 2010 and**

Thursday April 8th 2010

Workshop Time ___________________

Remember your pseudonym.

Pseudonym: ___________________________________

☐ Ticking this box signifies that I have read the Participant Information sheet associated with this research project and I give my consent for this work to be collected and analysed as part of the *Electricity and Magnetism Pedagogies for Pre-service Teachers project.*

This project has been approved by the Human Research Ethics Committee of the University of New England (Approval No. HE09/003 valid to 30/06/2010). Should you have any complaints concerning the manner in which this research is conducted, please contact the Research Ethics Officer at the following address: Research Services. University of New England. ARMIDALE. NSW 2351. Telephone: (02) 7673349; Facsimile: (02) 67733543; Email: Ethics@pobox.une.edu.au

You will use this workbook for the two workshops, today and next week. The workbook will be collected from you at the end of the workshop, copied, and returned to you at the commencement of the next workshop.

WORKSHOP 1.

1. Station: What's the Connection

On the bench are 8 numbered examples of different types of wire.

Description of the Wire (number)	**Where do you think this kind of wire is used?**	**What particular characteristic of this wire makes it suitable for the use you described?**
(space omitted here)		

2. Station: That's Shocking – conductivity and insulation

Step 1: Setup the **multimeter** (check your photocopy for the correct setup of the meter).
EXPLORE the items provided.
Share your findings with other group members.

Step 2: Write what you have learned in the space below.
(space omitted here)

Step 3: Comment on how this activity could help you achieve the following NSW Stage 3 syllabus dot point.

• *works collaboratively to research, develop a storyboard and a multimedia presentation for communicating about **electrical safety.***
(space omitted here)

---

3. Station: Connecting Energy

You are supplied with 3 'motors', 4 pieces of wire with alligator clips, a piece o plastic tubing, and one source of electricity. Connect two of the motors with the piece of plastic tube so that when one motor is running, it makes the other one rotate as well. Connect the other motors to the joined two in any combination you like using only the wires and clips provided.

Can you (from your recollection or experience in this activity) suggest/deduce any scientific principals or laws. Diagrams may help.
(space omitted here)

If the first motor is powered by electricity, what makes the other two go?
(space omitted here)

---

4. Station: Making Circuits

You have been given one 'C' cell, one piece of wire, and one light bulb. Devise a way of making the light bulb light.

Without looking at your neighbour, please draw a diagram of what you plan to try first.
(space omitted here)

Without amending your previous diagram, now that you have solved the problem and got it to work, please redraw and label your working design in the space below.
(space omitted here)

Report any difficulties you had in getting it to work.
(space omitted here)

---

5. Station: Making Electricity

Connect one wire from the coil to a connection on the meter. Connect the other wire from the coil to the other connection on the meter. Now….
With the different magnets,

Explore, explore, explore (play, play, play)

Get in an use your senses, observe (qualitative and quantitative), suggest, experiment with the different movements and positions of the magnets into, out of, fast, slow, stationary, outside of… the coil.

Can you (from your recollection or experience in this activity) suggest/deduce any scientific principals or laws.

---

6. Each of your groups has been given a **shaky torch**. In the space below, draw and label the torch and try to **explain what each of the components** you have labelled actually do.

(space omitted here)

Compare your explanations with other members of your group and in a separate list, record your agreed explanations of the workings of your labelled components.
(space omitted here)

WORKSHOP 2.

1. You remember seeing a great activity just using some wire, a nail and a battery. With these basic components the demonstrator was able to pick up a paperclip.

You are thinking about using this activity with your class and sit down with your colleagues to discuss the best way to do it.

Working collaboratively with the other three members of your group, make a device to attract and pick-up a paperclip using a metre of wire, a nail, and a 'C' cell.

In this workbook, in your own way (words, diagrams, labels etc.), please describe what is happening in your device to make it attract and pick-up a paperclip.
(space omitted here)

---

2. **Does it work as well without the nail in the centre of the coil? Try a different centre? Report on your findings.**

(space omitted here)

---

3. In the table below, list as many things as you can that involve the **use of magnets** in the first column, identify the type of magnet in the second column, and describe the purpose of the magnet in the final column.

Item using a magnet	Type/shape etc. of magnet	Purpose of the magnet
(space omitted here)		

4. **How would you explain each of these things to an alien (assuming a common language)?**

Magnet:

Electricity:

Charge:

Magnetic field:

Electric motor:

APPENDIX A.5

Electricity and Magnetism

LECTURE EDSE412

Tuesday April 27th 2010.

Workshop Time ____________________

Remember your pseudonym.

Pseudonym: ______________________________________

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This workbook will serve as source of data for my project, and for the recording of any notes, observations or responses to questions you feel appropriate. At the end of the lecture and workshop, with your permission, I will copy your responses and return the original workbook to you for your own reference.

Introduction

This project is all about providing you with knowledge about concepts and teaching strategies that will better prepare you to teach science competently and confidently as soon as you begin your teaching career.

The 5Es

During this lecture, we will discuss elements of the 5Es approach, and you are invited to record your notes in the pages that follow.

In light of the anticipated national curriculum, the Australian Academy of Science has developed and is promoting a series of K-6 units under the banner of Primary Connections. They have adopted the 5Es approach as a learning cycle:

> **ENGAGE**: To create interest and inspire the students and elicit prior knowledge;
>
> **EXPLORE**: To provide hands-on shared experiences of the phenomenon;
>
> **EXPLAIN**: To develop scientific explanations for their personal experiences in terms of conceptual understanding;
>
> **ELABORATE**: To extend or apply their understanding to a new context, or make connections to additional concepts through a student-planned investigation; and
>
> **EVALUATE**: To celebrate the learning, the students re-represent their understanding and reflect on their learning journey. It is in this stage that teachers actively collect evidence of achievement and outcomes.
>
> (Australian Academy of Science 2007)

Predict-Observe-Explain-Share

An integral component of the learning cycle is the application of a Predict-Observe-Explain strategy. In line with Constructivist principals of learning, incorporated in this strategy is a component that will involve you working collaboratively with your peers – a practise proven to be effective in real classrooms. This is called the SHARE component. The basic elements are:

Initially, you will work individually to:

> **PREDICT**: describe what you expect to be the outcome of specified activities;
>
> **OBSERVE**: record your observations of the actual event; and
>
> **EXPLAIN**: record an explanation of what happened in your own words, and identify how their prediction varied from the actual observation.

With your colleagues, you will then collaborate to:

> **SHARE**: discuss the variation between your observations and explanations, eventually arriving at an agreed, shared description.

- POES 1 – how do 2 bar magnets interact when you put their ends together? – like/unlike ends
- POES 2a – electromagnet (no core) surrounded by mini compasses
- POES 2b - electromagnet (iron nail core) surrounded by mini compasses
- POES 2c - electromagnet (iron nail core) surrounded by mini compasses – reverse wires in the battery to reverse the direction of the current
- POES 2d – testing different materials as the core of an electromagnet surrounded by mini compasses – which works best?
- POES 3a – investigate the interaction between an electromagnet and a fixed button magnet
- POES 3b - interaction between electromagnet and fixed button magnet – reverse wires

For each of the POES activities, record your predictions, observations and explanations in the tables below. Only after you have recorded your personal explanation, discuss your findings with other members of your group and arrive at an agreed explanation. Record the explanation in the table also.

Prediction	**Observation**	**Explanation**
(space omitted here)		
Negotiated and agreed explanation		
(space omitted here)		

(a table was provided for each of the seven POES)

Definitions

How would you explain these terms to a Year 4 student if they asked?

Electrical power

Volts

Amps

Watts

(each response was allocated 5 lines in the workbook)

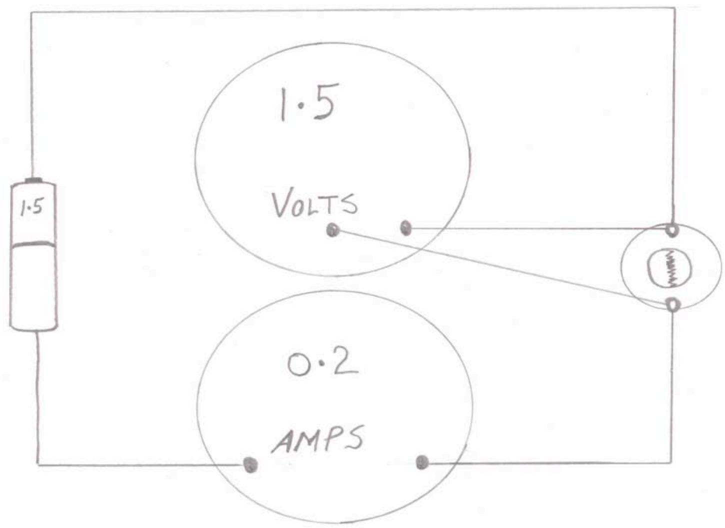
Measuring Electrical Power

To calculate electrical power, we multiply volts by amps.

Power = volts x amps

We can measure these two things in an electrical circuit with a **multi**meter.

The first thing we measure is voltage (set to V on the multimeter – attached across the thing we are measuring).
The second thing is the amps (set to A on the multimeter – in the flow of the electricity in the circuit.



Voltmeter connected across the Light bulb

In this example, the power of the light bulb is _____ volts x ______ amps = _______ Watts

In this workshop, YOU are going to do calculations for the power that is produced by some solar cells. You will also work out the power of some small electric motors.

Some examples

Power (Watts)	Volts	Amps	Found?
	12	5	Car lights
1000	250		Household bar radiator
60	250		Old light bulb
15	250		Fluorescent light
	12	9	Speakers
	3	.25	iPod
.36		.95	Mobile phone

Measuring Mechanical Power

We also have access to mechanical power

- power to move things
- power to push something (the power is needed to overcome what?),
- or lift something (the power is needed to overcome what?)

Mechanical power is dependent on what???

$$\textbf{Power} = \frac{\textbf{mass x gravity x height}}{\textbf{Time}}$$

For example:
What is the power of a motor that can pump 30 litres of water (30kG) up a 2m pipe in 1 minute (60 seconds)?

$$P = \frac{30 \times 10 \times 2}{60}$$

P = ________ W

WORKSHOP EDSE412

Tuesday April 27th 2010.

Workshop Time ____________________

Remember your pseudonym.

Pseudonym: ______________________________________

ACTIVITY 1: HOW DOES A COMPASS WORK?

Background Information

What is a compass? Does it always point north/south? What effect does bringing a magnet near a compass have? Can you make a compass? Can you see a magnetic field? Can you see the Earth's magnetic field?

These are the sort of questions you can expect to be asked by your students when you talk about magnets and compasses.

If you were told that a compass is simply a magnet suspended somehow so that it can move, how would you go about making one?

Equipment Provided:

Bar Magnets
Polystyrene Sheet
String
Sticky tape
A large dish

Use some or all of the equipment provided to make a compass. Draw your end product.

(space omitted here)

Magnetic Field

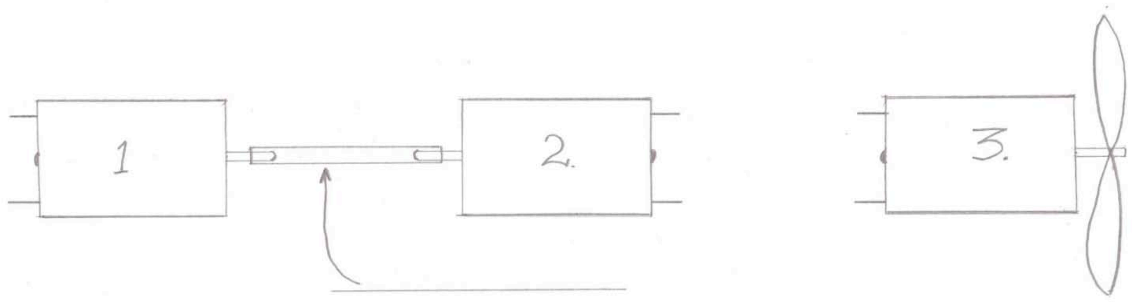
You have probably heard that the Earth has a magnetic field and that compasses line up with the Earth's magnetic field.

See if you can cause the compass that you made to change its alignment?
Describe what you do and the observations you make.

(space omitted here)

ACTIVITY 2: CONNECTING ENERGY

Consider the setup in the diagram below.



Describe what happens when each of 1, 2 and 3 are connected to a battery.
(space omitted here)

What would you call each of 1, 2 and 3.
(space omitted here)

If 2 is connected to 1 with a just a piece of plastic tube, describe what happens when 1 is connected to a battery (can electricity get from 1 to 2?).
(space omitted here)

If 3 is connected to 2 using wires and 2 connected to 1 using the tube and 1 is connected to a battery, describe what happens.
(space omitted here)

Provide an explanation in your own words.
(space omitted here)

Share your explanation with other members in your group and record your agreed explanation.
(space omitted here)

Where did the energy to run 3 come from?
(space omitted here)

Can you (from your recollection or experience) suggest/deduce any scientific principals or laws. Diagrams may help.
(space omitted here)

ACTIVITY 3: HOW EFFICIENT IS A SMALL ELECTRIC MOTOR?

Background Information

Recall the equation:

$$\text{Power} = \frac{\text{Mass X Gravity X Height}}{\text{Time}}$$

- **Power = Watts**
- **Mass = kiloGrams**
- **Gravity = 10m/s^2**
- **Height = Metres**
- **Time = Seconds**

The power that goes into the motor
We can calculate the power that goes into an electric motor using the equation P = VI. Some of this power going in us used up overcoming friction, making heat and noise.

We can calculate how much power the motor produces by lifting weights over a certain distance and timing how long it takes.

We can then compare the two to determine what percentage of the power going into the motor actually is used by the motor to lift something.

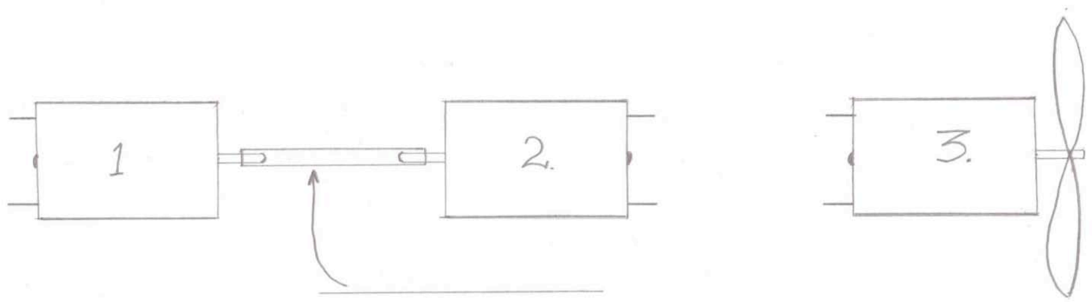
You are provided with the following equipment to conduct this investigation:

retort stand	2	1.5 V cell and holder	
bosshead	2	multimeter	2
clamp	2	wires with alligator clips	6
plastic holder	2	cotton thread	1.5m
Skewer		metre ruler	
plastic tube	5cm	Plasticine	
electric motor		scales	

On the last page of this workbook, discuss with your colleagues and design a step by step sequence you would recommend to your students to complete the assigned task.

ACTIVITY 4: POWER FROM THE TRIPLE MOTORS

Let us do some measurements of the motors set up in line.



Voltage into Motor 1	**Current (Amps) into Motor 1**	**Calculated Power into Motor 1**
(space omitted here)		
Voltage out of Motor 2	**Amps out of Motor 2**	**Calculated Power out of Motor 2**
(space omitted here)		
Voltage into Motor 3	**Amps into Motor 3**	**Calculated Power into Motor 3**
(space omitted here)		

Where did the power go?

If your car has a 12 volt electrical system, how much current (amps) passes through a 100W headlight?
(space omitted here)

Your domestic electricity supply is rated at 240V. How much current passes through a heater that has a power rating of 1000W?
(space omitted here)

How much electricity would a 600W microwave use if it was used to heat a cup of water for 1 minute? (Note 1KWh = 1000 watts used by an appliance for an hour.)
(space omitted here)

If 1 KWh costs 25cents, how much does it cost to run a 1000W heater for 4 hours?

ACTIVITY 5: MAKING AN ELECTRIC MOTOR.

We are going to allow electricity to flow intermittently through a coil of wire and allow it to interact with a permanent magnet.

Step 1: make your coil – using 1m of enamelled copper wire

Step 2: shape your paperclips so they will be able to cradle your coil.

Step 3: tape the paperclips to a size 'C' dry cell so that the coil spins freely (balancing required). Place a small piece of blue tac or plasticine on the bottom of the magnet so it is secure.

Step 4: Place a button magnet on the top of the cell and below the coil. If necessary, tap the coil to start the motion.

Step 5: If your motor does not work, look around and seek the advice of your colleagues.

Equipment provided:

1m enamelled copper wire	2 paper clips
1 size 'C' dry cell	insulation tape
sand paper	blue tac

Draw and LABEL your final motor – in your own words, try to explain how it works.

(space omitted here)

What was the most interesting part of building the motor for you?

(space omitted here)

Can you think of anything you could do with your motor to make it a better activity with your students?

(space omitted here)

Deconstruction an Electric Motor
Now that you have build a working model of an electric motor, how similar is it to the real thing. You are provided with a small 1.5V electric motor. Pull it to pieces and draw and label the components. Now try to describe the purpose of each of the components and match them to the components of the model you built.